42. CLOSE BINARY STARS (ETOILES BINAIRES SERREES)

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1. Introduction

During the XIXth General Assembly of the IAU in Delhi the number of members of Commission 42 increased to 260. This simply reflects the growing interest and importance of our field. Growing is not only the number of astronomers involved in research on CBS but also the number of papers resulting from that activity. As an example one can quote the numbers of papers listed during the last few years in Sections 117 (Close Binaries), 119 (Eclipsing Binaries), and 120 (Spectroscopic Binaries) of the *Astronomy and Astrophysics Abstracts*: 705(1982), 775(1983), 836(1984), 1080(1985), and 911(1986); note that many additional references could be added to these numbers from other sections. Naturally, such numbers alone do not reflect the quality and even less so the position and significance of the CBS field. Here one could perhaps mention an impressive record of successful research proposals involving requests for the observing time on large, ground based telescopes and on space instruments. Indeed, in spite of a very strong competition from other fields, programs involving CBS are usually placed very high on the priority lists (cf. Sections 2D and 2E). Obviously, the close binary systems, their evolution, and the physical processes which occur in them (accretion, stellar winds, nuclear burning, etc) appear interesting and important not only to those who are involved in their studies but also to astronomers from other fields.

No large symposium devoted exclusively to CBS has been organized during the past triennium. A proposal for an IAU Symposium on *Circumstellar Matter in Close Binary Systems*, to be held in Canada, in 1987, has been submitted in 1985 but did not meet an approval by the IAU Executive Committee. The Commission's Organizing Committee, while considering its possible re-submission, decided not to do so, but rather to concentrate in the future on smaller, more specialized meetings. (In fact, some OC members expressed an opinion that our field is already too large for a successful, working meeting involving *all* types of CBS). The Commission co-sponsored IAU Colloquium No.93: *Cataclysmic Variables*, Bamberg, June 1986; IAU Colloquium No.97: *Wide Components in Double and Multiple Stars*, Brussels, June 1987; and IAU Colloquium No.103: *The Symbiotic Phenomenon*, Toruń, August 1987. The Commission is also a sponsor of the IAU Coll. No.107: *Algols*, to take place in Victoria, in August 1988.

There have been very many meetings not sponsored by our Commission, but devoted - partly or completely - to the field of CBS and attended or co-organized by members of our Commission. Their list, obviously incomplete, includes: IAU Symp. 125: *The Origin and Evolution of Neutron Stars*, Nanjing, May 1985; IAU Coll. 89: *Radiation Hydrodynamics in Stars and Compact Objects*, Copenhagen, June 1985; IAU Coll. 92: *Physics of Be Stars*, Boulder, August 1986; IAU/COSPAR Coll.: *Physics of Compact Objects: Theory vs. Observations*, Sofia, July 1987; Japan/US Seminar: *Compact Galactic and Extragalactic X-Ray Sources*, Tokyo, January 1985; ESA Workshop: *Recent Results on Cataclysmic Variables*, Bamberg, April 1985; NATO Workshop on the *Evolution of Galactic X-ray Binaries*, Rottach-Egern, June 1985; Symp.: *Critical Observations vs. Physical Models for Close Binary Systems*, Beijing, November 1985; ESA Workshop: *Physics of Accretion onto Compact Objects*, Tenerife, April 1986;

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Workshop: *High Energy and Ultra High Energy Accreting Sources*, Vulcano, May 1986; *AAVSO Variable Star Symposium*, Cambridge, August 1986.

Many good review articles have been published in various journals and in the conference proceedings volumes (cf. references in sections below). New books were: J.E. Pringle and R.A. Wade, eds.: *Interacting Binary Stars* (Cambridge U.Press, 1985) and J. Frank, A.R. King, and D.J. Raine: *Accretion power in astrophysics* (Cambridge U.Press, 1985). Among the catalogues one should mention the appearance in 1985 of Vol.1 (Andromeda-Crux) and Vol.2 (Cygnus-Orion) of the 4th edition of the *General Catalogue of Variable Stars*, published by Dr. P.N. Kholopov and his collaborators.

As described in the last Report, our Commission endorsed a proposal for an IAU grant to support the publication by AAVSO of its observations of cataclysmic variables. It is now satisfying to report the publication by J.A. Mattei *et al.* of *AAVSO Monographs* No.1, SS Cyg and No.2, U Gem.

The *Bibliography and Program Notes on Close Binaries*, edited, published, and distributed by Dr. Tibor Herczeg (University of Oklahoma and Remeis-Sternwarte), continues to play its very important and useful role. During the time covered by this Report Nos. 41-44 were published, the contributors to the *Bibliography* being: K.D. Abhyankar, B. Cester, O. Demircan, D.S. Hall, M. Kitamura, H. Mauder, R. Olowin, J. Papousek, M.B.K. Sarma, C.D. Scarfe, A. Schulberg, R.F. Sisteró, F. Van'tVeer, M. Vetesnik, and A. Yamasaki.

This Report, covering the interval from July 1984 to June 1987, is essentially similar to previous ones, with some sections having been merged and some new sections being added. The emphasis is on major highlights and most crucial developments and prospects in the field. With few exceptions, no full lists of references are being given; for a complete bibliography the reader is referred to the *Astronomy and Astrophysics Abstracts*. The President acknowledges with gratitude the cooperation of the co-authors, who prepared various sections, as indicated below.

Throughout the Report the following abbreviated references are used:

AA = *Acta Astron.*
AAp = *Astron. Astrophys.*
AApSup = *Astron. Astrophys. Suppl. Ser.*
AASin = *Acta Astron. Sinica*
AApSin = *Acta Astrophys. Sinica*
AdvSpRes = *Adv. Space Research*
AJ = *Astron. J.*
AN = *Astron. Nachr.*
AnnRevAAp = *Ann. Rev. Astron. Astrophys.*
AnnTokyo = *Ann. Tokyo Astron. Obs. Second Ser.*
ApJ = *Astrophys. J.*
ApJSup = *Astrophys. J. Suppl. Ser.*
ApL = *Astrophys. Lett.*
ApSpSc = *Astrophys. Space Sci.*
ATs = *Astron. Tsirk.*
AZh = *Astron. Zh. Akad. Nauk USSR*
BAAS = *Bull. American Astron. Soc.*
BAC = *Bull. Astron. Inst. Czechoslovakia*
BullAbas = *Bull. Abastumani Astrophys. Obs.*
CommAp = *Comments on Astrophys.*
IAUColl = *IAU Colloquium, followed by a number*
IAUC = *IAU Circular*
IAUSymp = *IAU Symposium, followed by a number*
IBVS = *Inf. Bull. Variable Stars*
IzvKrym = *Izv. Krymskoi Astrofiz. Obs.*
JApA = *J. Astrophys. Astron.*
JRASC = *J. R. Astron. Soc. Canada*
MittAG = *Mitt. Astron. Ges.*
MN = *Mon. Not. R. Astron. Soc.*
Obs = *Observatory*
PASJ = *Publ. Astron. Soc. Japan*
PASP = *Publ. Astron. Soc. Pacific*
PisAZh = *Pis'ma v Astron. Zh.*
PRL = *Phys. Rev. Letters*
PubDAO = *Publ. Dominion Astrophys. Obs.*
QJRAS = *Quart. J. R. Astron. Soc.*
RevMex = *Revista Mexicana Astron. Astrofis.*

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2. Observational Data

A. PHOTOMETRIC OBSERVATIONS AND METHODS AND RESULTS OF LIGHT CURVE ANALYSIS (R.H. Koch)

This summary was compiled from materials held at Pennsylvania no later than June 30, 1987. It is styled so as to be similar to Sections 2 and 3A of the 1985 Report.

The recent history of programs leading to photoelectric light curves is compiled in Table 1. It is important to understand why photoelectric activity seems not to have continued its historical increase during the last triennium. An acceptance criterion somewhat more severe than hitherto has been imposed on the literature references counted in the first entry for 84-87: unless abstracts, administrative reports and announcements give a quantitative expression of the data that have been obtained, they have been excluded from the count. This achieves nearly a 6% diminution with respect to the last previous tally. Under-reporting must also be considered. Once more it is true that not all literature citations are among the Pennsylvania holdings or those that are otherwise accessible. However, this deficiency appears not to be significantly worse than previously. The 81-84 reporting interval is about 11% longer than usual and the present interval correspondingly shorter. When these factors are accounted for and coupled to the 6% diminution described above, it is seen that activity has actually increased but by a sensibly smaller percentage than familiarly for almost the ten previous years.

Table 1. Photoelectric Observing for the Past Four Triennia

	75-78	78-81	81-84	84-87
References for photoelectric data	346	564	713	565
Close binaries observed	209	342	455	339
Binaries not observed previous 3 years	184	240	313	187
Northern systems ($\delta > +23°$)	88	120	197	149
Equatorial systems	50	77	135	123
Southern systems ($\delta < -23°$)	35	76	123	67

Prorated as just described, the number of binaries observed has remained nearly constant at about 400 per triennium for 6 years. This has been possible because sustained productivity from the northern sky and a slight increase from the equatorial region have compensated for the considerable decrease of the contribution from the far southern sky. (It must be remembered that more systems than formerly are not observed by ground-based workers so simply counting by declination leads to a small bias). Perhaps many southern systems have not yet emerged from the pipeline. But it does seem clear that the growth rate sustained for the decade beginning in 1975 is over at least for now. A more detailed understanding of this effect will emerge later in this Report, but a final remark will forecast the result. Even though observers have chosen not to repeat light curve coverage for many familiar binaries, in the last 3 years they have actually observed more than 90 systems never observed before.

As in previous reports it is possible to summarize the light curve analyses that have appeared in the last triennium. As before also, some small number of references could not be checked from local holdings and these were omitted from the listing which appears in Table 2.

Table 2. Photometric Solutions

AB And *ApSpSc 127*,153, *AN 307*,17; AN And *AnnTokyo 21*,311; BL And *AA 35*,327; CN And *AA 33*,345, *PASP 97*,310; DS And *AN 304*,263; RY Aqr *AAp 172*,155; ST Aqr *AA 35*,327, *ApSpSc 117*,375; CX Aqr *MN 223*,607; DV Aqr *PASP 97*,62; OO Aql *ApSpSc 114*,23;

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V1343 Aql *MN 210*,279; SS Ari *AA 34*,445; SX Aur *MN 224*,649; TT Aur *MN 211*,39, *MN 211*,229, *MN 224*,649, *AAp 162*,62; ZZ Aur *AJ 90*,115, *AASin 24*,217; AH Aur *AA 33*,159; HS Aur *AJ 91*,383; IM Aur *AApSup 60*,389; LY Aur *ApJ 298*,345; ε Aur *BAAS 15*,925, *ApSpSc 123*,31; XY Boo *ApSpSc 107*,347; TU Cam *AnnTokyo 21*,229; AO Cam *ApSpSc 113*, 25, *PASP 97*,648; AT Cam *AAp 141*,266, *AApSin 5*,26, *ChinAAp 9*,139; AZ Cam *AAp 141*, 266, *AApSin 5*,26, *ChinAAp 9*,139; S Cnc *AJ 90*,504; AC Cnc *AZh 63*,123; AH Cnc *AApSup 58*,405; RS CVn *ApSpSc 105*,259; BI CVn *BAAS 18*,850; GZ CMa *AJ 90*,1324; XZ CMi *AAp 96*,415; GL Car *AAp 161*,275; OY Car *AAp 130*,81; V348 Car *MN 213*,75; SX Cas *BAC 36*,153; TV Cas *AA 34*,47; TX Cas *MN 216*,663; XX Cas *IBVS* 3001; YZ Cas *AZh 63*,690; AE Cas *AA 34*,281; AO Cas *ApSpSc 105*,259; DO Cas *AA 35*,327, *ApSpSc 119*,381; HT Cas *ApJ 305*,740, *AA 36*,395, *AAp 130*,81; MN Cas *AnnTokyo 21*,229; V364 Cas *ApSpSc 106*, 273; V368 Cas *IBVS* 2944; V375 Cas *AApSin 6*,185; V523 Cas *AAp 170*,43; RR Cen *ApSpSc 127*,153; ST Cen *AnnTokyo 21*,229; SV Cen *ApSpSc 117*,351; SZ Cen *AnnTokyo 21*,311; V757 Cen *AApSup 58*,405, *AA 34*,217; V758 Cen *ApSpSc 109*,271; V779 Cen *AZh 63*,494; U Cep *PASP 96*,162, *ApSpSc 125*,219; RS Cep *AJ 89*,562, *AJ 91*,1421; VW Cep *ApSpSc 105*,259, *AApSup 58*,261; WX Cep *AnnTokyo 21*,229; WZ Cep *AA 36*,105; XX Cep *AAp 156*, 38; XZ Cep *MN 211*,39; AH Cep *MN 223*,513; BE Cep *PASP 98*,662; DH Cep *IBVS* 2932; EG Cep *AA 34*,433; EI Cep *Izv.Engel.Kazan 47*,19; EK Cep *AJ 89*,1256; ER Cep *AApSup 58*,405; GW Cep *AA 34*,217; TX Cet *ApSpSc 117*,375; VY Cet *AAp 161*,264, *RevMex 10*, 283; YY Cet *MN 218*,159; Z Cha *AA 36*,211, *AAp 130*,81; RS Cha *AnnTokyo 21*,311; YZ Cha *AJ 92*,1420; RW Com *BAAS 18*,696; RZ Com *PASP 96*,646; RT CrB *ApSpSc 112*,133; α CrB *AJ 91*,1428; RV Crv *MN 223*,595; SS Cyg *PisAZh 12*,219; CG Cyg *AJ 90*,761, *PASP 99*,410; CI Cyg *IzvKrym 68*,108, *AA 33*,403; KR Cyg *ApSpSc 117*,351; MR Cyg *ApJ 316*, 754; V367 Cyg *ApJ 313*,801; V380 Cyg *AAp 141*,39; V388 Cyg *ApSpSc 117*,351; V453 Cyg *AnnTokyo 21*,229; V478 Cyg *AnnTokyo 21*,229; V541 Cyg *ATs* 1270; V548 Cyg *AA 33*,163; V909 Cyg *ApSpSc 123*,305; V1143 Cyg *AAp 141*,1; V1357 Cyg *AZh 60*,727; V1727 Cyg *MN 218*,63; DM Del *AApSup 67*,87; AA Dor *AA 34*,381; AR Dra *AnnTokyo 21*,229; BV Dra *AJ 92*,666; BW Dra *AJ 92*,666; RU Eri *PASJ 36*,277; WX Eri *AnnTokyo 21*,229; YY Eri *AA 36*,79, *AAp 159*,142; AS Eri *AAp 141*,1; U Gem *AA 34*,93; RY Gem *ApSpSc 105*,259; IR Gem *ApJ 282*,236; TT Her *AA 35*,327; AK Her *PASP 97*,1005; V624 Her *AJ 89*,1057; u Her *MN 211*,943; SY Hor *RevMex 10*,283, *AAp 161*,264; FG Hya *ApSpSc 127*,153; KW Hya *AAp 130*,102 (not KM Hya), *AAp 175*,355; Chi^2 Hya *AnnTokyo 21*,229; Y Hyi *ApSpSc 119*, 345; SW Lac *PASP 96*,634, *PASP 96*,646, *ApSpSc 114*,23, *AA 36*,79, *AApSup 67*,365; VY Lac *AA 34*,207; AR Lac *AA 34*,291, *AJ 91*,1438; CM Lac *Izv.Engel.Kazan 47*,19; CO Lac *Izv.Engel.Kazan 47*,19, *AnnTokyo 21*,229; T Leo *ApJ 276*,305; UV Leo *AnnTokyo 21*,229; UZ Leo *ApSpSc 127*,153; XY Leo *AA 33*,277; AM Leo *PASP 96*,646; GX Lib *AJ 90*,2581; FT Lup *AA 36*,113, *MN 208*,135, *MN 220*,883; SW Lyn *AA 35*,327; TZ Lyr *AA 35*,327; FL Lyr *AJ 91*,383; TZ Men *AAp 175*,60; RU Mon *AZh 63*,288; RZ Oph *PASP 96*, 737, *AAp 168*,72; V451 Oph *ApSpSc 106*,93, *AAp 167*,287; V566 Oph *ApSpSc 114*,23, *AA 36*,275; V839 Oph *ApSpSc 114*,23; V2051 Oph *MN 222*,871; VV Ori *AnnTokyo 21*,229, *AJ 93*,950, *ApSpSc 127*,79; ER Ori *AAp 155*,46; EW Ori *AJ 91*,383; U Peg *AApSup 57*,487, *PASP 96*,646, *ApSpSc 121*,61; BB Peg *AJ 90*,515; BO Peg *PASP 98*,1325; BX Peg *AJ 90*, 515, *AA 34*,217; IP Peg *MN 222*,655, *MN 224*,1031, *PisAZh 11*,696, *AAp 130*,81; AG Per *ApSpSc 129*,187; DM Per *MN 222*,167; IQ Per *ApJ 295*,569; KR Per *AJ 90*,1855; LX Per *ApSpSc 112*,273; β Per *ApSpSc 108*,227, *ApSpSc 123*,305; AI Phe *ApJ 282*,748; AU Phe *RevMex 10*,283; SZ Psc *ApSpSc 105*,23; PV Pup *AAp 132*,219; U Sge *ApSpSc 125*,219; V Sge *ApJ 306*,618; WY Sge *ApJ 282*,763; V760 Sco *AAp 151*,329; V906 Sco *AnnTokyo 21*,229; RT Scl *MN 223*,581; VZ Scl *MN 225*,43; AU Ser *AA 36*,113; CD Tau *ApSpSc 123*, 305; GR Tau *PASJ 36*,175; 33 Tau *AJ 90*,1334; AQ Tuc *MN 223*,581; CF Tuc *ApSpSc 133*, 45; W UMa *ApJ 316*,389, *AA 36*,79; XY UMa *ApSpSc 128*,369; BE UMa *ApJ 316*,399; DN UMa *ApSpSc 125*,181; RU UMi *AA 35*,327; GP Vel *ApJ 280*,259, *AZh 63*,690; AG Vir *AA 36*, 121, *AApSup 61*,313; AH Vir *PASP 96*,646, *AA 34*,217; AX Vir *AJ 90*,115, *AApSin 5*,124; FO Vir *AJ 91*,1221; HD1826 *AApSup 66*,303; HD27130 *AJ 93*,1471; HD47755 *AJ 91*,590; HD149779 *AAp 167*,53; HD164270 *PASP 98*,1170; HD184035 *IBVS* 2552; HD199497 *ApSpSc 115*,309; HR3337 *JRASC 79*,119; HR7551 *AAp 139*,123; ADS 9019B *AJ 90*,346; A0620-00 *ApJ 308*,110; PG1012-029 *ApJ 276*,233; 1E1048.5+5421 *ApJ 314*,641; SK188 *ApJ 292*,511; AGK3-0 965 *RevMex 13*,149.

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All the analyses enumerated in Table 2 have been achieved by one or more analytical/synthetic procedures. Over the past 20 years there has been a substantial flux in the availability and acceptability of these methods. A portion of this history may be seen in Table 3.

Table 3. Percentages of Light Curves Studied by Different Computational Procedures

	75-78	78-81	81-84	84-87
A - Budding	2 %	0 %	2 %	0 %
B - Eaton-Hall	1 %	0 %	1 %	2 %
C - Hill	2 %	2 %	1 %	6 %
D - Kitamura	3 %	4 %	0 %	2 %
E - Kopal (alpha functions)	1 %	0 %	0 %	0 %
F - Kopal (frequency domain)	7 %	17 %	15 %	12 %
G - Lavrov	2 %	1 %	0 %	2 %
H - Miscellaneous	5 %	14 %	20 %	19 %
I - Mochnacki-Binnendijk-Nagy	3 %	0 %	0 %	3 %
J - Ruciński	3 %	1 %	3 %	3 %
K - Russell-Merrill	23 %	11 %	11 %	6 %
L - Soderhjelm	4 %	0 %	0 %	0 %
M - Nelson-Davis-Etzel (sphere, EBOP)	1 %	2 %	3 %	8 %
N - Wilson-Devinney	13 %	14 %	22 %	27 %
O - Wood	30 %	34 %	21 %	8 %
P - Yamasaki	0 %	0 %	1 %	2 %

Three preliminary remarks may be made: (a) because of redundant applications the number of analyses is measurably greater than the number of binaries analyzed; (b) the *Miscellaneous* category percentage for 81-84 is diminished from its value in the preceding Report because 1% contributors appear explicitly above; and (c) a zero entry may not mean that the method was completely unused but only that usage did not amount to 1% of the total. Most of the obvious trends reflect the convenience and availability of, and confidence in the assorted codes. During the 78-84 interval something approaching production line use of the Wilson-Devinney and Wood codes was brought to bear on numerous archival light curves. It appears that students of light curves subsequently concluded that the flexibilities and modeling returns offered by Wilson-Devinney procedures more than compensate for the less-than-modern documentation associated with this program. There also remain serious concerns about the parameter resolution possible with this code for contact and over-contact pairs. The only other significant contenders for abundant use in the near future appear to be the frequency domain procedure and EBOP. The former has found favor with the Manchester staff and their present and former students and in Japan. For limited applications EBOP offers two impressive advantages: (a) it has been forcefully recommended after careful tests on feebly-interacting systems and (b) on diskette it can run efficiently at PC terminals. Finally, since 1985 60% of the catchall category of *Miscellaneous* procedures has been applied to binaries containing collapsed objects. Almost all of these modelings have concerned themselves with the structure and photometric activity of the disk embedding the collapsed member.

One may make some judgments on why the trends in Table 3 have run their courses. The student of light curve must have confidence in the integrity of the code that he is using and thus the numerous tests performed on archival light curves by the Trieste group have served this useful purpose. He should also have convinced himself that the mathematical order of the procedure and grid fineness are sufficient for the light curve under study and that an acceptable criterion prevents over-discussion. This statement should not mislead one into supposing Table 3 (which is not utterly exhaustive) to be concerned only with computational procedures (and it must be admitted that differences between some of the proce-

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dures are slight). For light curve study physical realism is the only endpoint concern and so the analyst of light curves makes decisions which are not intrinsically mathematical or calculational. By reference to the letter key in Table 3 consider the possible bases for the figures of the component stars: (a) spheres with no specified structure (e.g. M); (b) similar ellipsoids of rotation, similarly oriented with no specified structure (e.g. K); (c) tri-axial ellipsoidal polytropes (e.g. O); and (d) Roche geometrical, gravitationally-specified volumes (e.g. N). Even if all the categories of Table 3 were expressed in this enumeration, a complete understanding of the procedures of Table 3 would still not be summarized so succinctly. The entries of that table further distinguish themselves mutually by the choice of function for the stellar irradiance, the device for handling the radiative interactions between the stars, and the method(s) chosen for handling non-theoretical effects. It is very common to make choices of procedure on the basis of information (e.g. spectrographic or photoelectric mass ratios, magnetic field strength) that cannot be recovered even indirectly from the photometric measures.

Table 4 shows the trends of the kinds of binaries which have engaged the interests of workers for more than a decade. In view of the asymmetries which are so conspicuous for contact systems and for above-the-MS pairs, it isn't clear that the slightly evolved identification with RS CVn-type display is justified, but this category is a small one anyhow. For the rest it is clear what has happened: systems which one used to call Algol- and β Lyr-type objects are not viewed with the interest which they once commanded but attention is sustained for contact pairs and binaries with collapsed stars.

Table 4. Percentages of Evolutionary Configurations among Solutions of Binary Light Curves

	75-78	78-81	81-84	84-87
Numbers of binaries	173	211	215	183
Mostly non-contact, ZAMS to TAMS	33 %	22 %	16 %	28 %
Near MS contact	21 %	29 %	37 %	35 %
Slightly evolved, e.g. RS CVn syndrome	4 %	7 %	6 %	5 %
Substantially evolved, but still non-degenerate	37 %	34 %	24 %	20 %
Substantially evolved, with collapsed component	5 %	9 %	17 %	12 %

It is impossible to avoid calling explicit attention to the last citation in Table 2. Any interpretation of light variability as due to orbiting or passing clouds occulting a star or stars represents a possible application of light curve procedures reminiscent of those used to study atmospheric eclipse phenomena.

B. SPECTROSCOPIC AND SPECTROPHOTOMETRIC OBSERVATIONS (A.H. Batten)

Spectroscopic and spectrophotometric studies during the past triennium are listed in Table 5. The format is the same as has been used in recent reports. An asterisk after a reference indicates that the paper contains an "orbital study". The quality of such studies, however, varies widely. Some of the papers cited present evidence *against* the supposed duplicity of the stars concerned. Some of the stars are included in the Table, as binaries, on the strength of weak or indirect evidence; e.g. the symbiotic spectra of some objects seem best explained by the existence of a companion, even if no certain velocity variations have been detected. The Table is about half as long again as that in the last volume of these *Transactions*, impressive evidence - despite the foregoing *caveats* - of the level of activity in the field. Investigations of the X-ray and γ-ray sources that are based only on observations from those two regions of the electromagnetic spectrum have been omitted from the Table. This somewhat arbitrary limitation of the term "spectroscopy" is based on the assumption that such studies will be more adequately dealt with elsewhere in the report. Studies of novae and nova-like var-

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iables that are concerned only with the progress of individual outbursts, rather than with the presumed duplicity of the star, have also been omitted. There are no references to the IAU Circulars or to abstracts which have been superseded by an easily indentifiable full paper. The Cepheid variables included are not there by error. A growing number of such stars is now recognized to belong to binary systems.

Table 5. Spectroscopic and Spectrophotometric Studies

Z And *IBVS* 2844; RX And *AAp 140*,345; DS And *BAAS 18*,682; EG And *ApJ 295*,620*, *AJ 91*,1400; ET And *AN 305*,79, *306*,329*; KX And *BAC 36*,313; ∂ And *MN 224*,93; Lambda And *AA 36*,369, *ApJ 281*,286; o And *ApSpSc 100*,13*; QS Aql *BAAS 19*,709*; V794 Aql *PASP 97*,1189; V1182 Aql *MN 225*,961*; V1315 Aql *ApJ 301*,240*; V1343 Aql (SS433) *ApJ 308*,152, *AZh 63*,94; 5 Aql *ApJSup 59*,229*; R Aqr *PASP 98*,118*; BW Aqr *AApSup 69*, 397*; CX Aqr *MN 223*,607*; FF Aqr *BAAS 18*,983; μ Aqr, 32 Aqr *ApJSup 59*,229*; TT Ari *PASP 97*,847*, *98*,507*, *ApJ 290*,707*; UX Ari *AJ 92*,1403; VY Ari *BAAS 19*,709; 29 Ari *PASP 98*,468*; 66 Ari *Obs 104*,69; SS Aur *AJ 92*,658*; TT Aur *AAp 162*,62*, *MN 224*, 649*; HS Aur *AJ 91*,383*; IM Aur *AJ 92*,441; α Aur *AJ 90*,1503*, *JApA 7*,45, *IBVS* 2937; ϵ Aur *PASP 97*,1163, *98*,389 and 637, *AAp 144*,395, *PASJ 39*,135, *AASin 26*,144, *AApSin 5*,180; Dzeta Aur *BAAS 17*,552, *AAp 170*,70; V363 Aur (Lanning 10) *ApJ 307*, 760*; TY Boo *BAAS 19*,643*; Kappa² Boo *AJ 91*,1416*; 6 Boo *JApA 6*,77*; 44 i Boo *AApSin 5*,36; AN Cam *AApSup 67*,161*; α Cam *PisAZh 12*,305*; S Cnc *ApJ 285*,208*; AC Cnc *ApJ 280*,235*; Y CVn *BAC 35*,74; TX CVn *AJ 91*,1400*; R CMa *ApJ 297*,250*; EZ CMa *AJ 91*,925, *MN 222*,809, *JApA 7*,305; GZ CMa *AJ 90*,1324*; ZZ CMi *PASP 96*,894; Dzeta Cap *PASP 96*,226; DW Car *RevMex 10*,323*; EM Car *PASP 98*,788*; HH Car *RevMex 11*,99*; V348 Car *MN 213*,75*; RX Cas *MittAG 62*,275, *PisAZh 12*,212*; PV Cas *AJ 93*, 672*; V373 Cas *AAp 171*,123*; V523 Cas *AJ 90*,354*; V651 Cas *IBVS* 2868*; RR Cen *MN 209*,645*; V834 Cen *MN 224*,987, *ApJ 285*,214, *ApSpSc 131*,613; α Cen *AAp 158*,273, *165*,126; Nu Cen *AA 35*,395*, *ApJSup 64*,487*; 4 h Cen *ApJSup 64*,487*; RS Cep *AJ 93*, 171; VW Cep *IBVS* 2711, *AJ 93*,672*; XZ Cep *ATs* 1275, *BullAbas 58*,45*, *AZh 62*, 938; AH Cep *MN 223*,513*; CQ Cep *IAUSymp 88*,117*, *AAp 134*.45*, *BullAbas 58*,25*, *ApJ 265*, 961*, *JApA 7*,171*; DH Cep *BAAS 19*,714; WW Cet *AJ 90*,2082*; YY Cet *MN 218*,159*; AY Cet· *ApJ 295*,153*; 5 Cet *PASP 97*,355*; Z Cha *MN 225*,551*; TV Col *ApJ 280*,729; RW Com *AJ 90*,109*; T CrB *AJ 91*,125*; α CrB *AJ 91*,1428*; θ CrB *IBVS* 2801; σ² CrB *BAAS 16*,473, *AJ 89*,1740*; RV Crv *MN 223*,595*; W Cru *MittAG 62*,275; VY Cru *ApJSup 56*,295; AI Cru *MN 226*,879*; SS Cyg *BAAS 18*,945, *ApJ 286*,747*, *300*,794*, *305*,732*; CG Cyg *AJ 90*,761*; CH Cyg *ApSpSc 102*,123, *116*,355, *131*,733, *IBVS* 2610, 2866, 2921, 2935, *PASJ 36*,567, *AnnTokyo 20*,75, *AAp 156*,186, *159*,117, *ESA SP-218*,K407; CI Cyg *AA 35*,65, *AAp 140*,91; V367 Cyg *ATs* 1284; V380 Cyg *AAp 141*,39*; V444 Cyg *ApJ 313*, 358; V448 Cyg *AZh 63*,702; V729 Cyg *AAp 143*,209; V1016 Cyg *AAp 142*,85; V1143 Cyg *AAp 174*,107*; V1357 Cyg (X-1) *BAAS 16*,407, *PisAZh 10*,756; V1727 Cyg *MN 218*,613*; 31 Cyg *ApJ 281*,751, *BAAS 19*,707, *AAp 170*,70; 32 Cyg *ibid.*, *AASin 25*,56; CM Del *AJ 90*,643*; UX Dra *BAC 35*,65; UZ Dra *AApSup 65*,97*; AB Dra *AJ 90*,2082*; AG Dra *AJ 91*, 1400*; BF Dra *AApSup 59*,357*; BP and BW Dra *PASP 98*,92*; α Dra *PASP 99*,130; Nu² Dra *ApJSup 59*,229*; Chi Dra *AJ 93*,1236*; RU Eri *PASJ 36*,277*; YY Eri *AAp 159*, 142*; EF Eri *MN 212*,609*; EI Eri *BAAS 19*,708; Dzeta Eri *ApJSup 59*,229*; RX Gem *PASP 99*,274; RY Gem *AJ 93*,440; IR Gem *ApJ 282*,236*; *σ Gem BAAS 17*,588, *IBVS* 2937; 65 Gem *JRASC 80*,91*; Z Her *BullAbas 58*,163; YY Her *AAp 135*,410; AH Her *MN 219*, 791*, *AAp 172*,187; DQ Her *ApJ 281*,194; HZ Her *ApJ 292*,670*; V533 Her *PASP 99*,57*; V795 Her *AJ 91*,940; Iota Her *AJ 89*,1876; 68 u Her *MN 211*,943*; 89 (V441) Her *PASP 96*,641*; 96 Her *IBVS* 2778*; 105 Her *ApJ 302*,764*; 108 Her *ApJSup 59*,229*; 112 Her *BullAbas 58*,265*; RW Hya *AJ 91*,1400*; TT Hya *BAAS 18*,976, *19*,708; EX Hya *ApJ 317*, 765; EZ Hya *MN 209*,645*; 21 (KW) Hya *AAp 130*,102*; VW Hyi *MN 212*,645, *225*,113; RT Lac *AJ 90*,499, *91*,583*; AR Lac *IBVS* 2579, *AAp 176*,267; X Leo *AJ 92*,658*; XY Leo *ApJ 285*,683*, *AAp 35*,29, *ApJ 317*,333* (quadruple system); DH Leo *AJ 89*,683*; 10 Leo *Obs 105*,7*; 93 Leo *IBVS* 2937; ST LMi *MN 226*,209*; UZ Lib *ApJ 285*,202*; GX Lib *AJ 90*,2581*; ∂ Lib *ATs* 1420; SZ Lyn *AApSup 57*,249*; FL Lyr *AJ 91*,383*; β Lyr *BAC 37*,42, *AJ 90*,773; Dzeta¹ Lyr *ApJSup 59*,229*; TY Men *AA 34*,345; TZ Men *AAp 175*,60*; AU Mon *BAAS 19*,713; AX Mon *RevMex 10*,229; BX Mon *AAp 153*,35*;

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V641 Mon *ApJ 288*,731; V644 Mon *BAAS 19*,708; 2 Mon *ApJSup 59*,229*; 18 Mon *Obs 104*, 267*; SY Mus *PASP 97*,268; GR Nor *Obs 104*,221; U Oph *BAAS 19*,709*; RS Oph *AAp 167*, 91, *PASP 98*,875, *AJ 91*,1400*; RZ Oph *AAp 168*,72*; V380 Oph *AJ 90*,643*; V426 Oph *ApJ 301*,L29*; V451 Oph *AAp 167*,287*; V502 Oph *MN 209*,645*; V508 Oph *PASP 98*,577*; V986 Oph *JRASC 79*,236*; V2051 Oph *AAp 154*,197*; 70 Oph *PASP 96*,903*; CN Ori *ApSpSc 131*,501*; EW Ori *AJ 91*,383*; Iota Ori *Obs 107*,5*; Psi Ori *PASP 97*, 428*; 64 Ori *AJ 92*,1162*; AR Pav *MittAG 62*,275; U Peg *PASP 97*,1086*; EZ Peg *Obs 105*,81*, *PASP 97*, 72; II Peg *AAp 176*,267; IP Peg *MN 224*,1031*; Iota Peg *PASP 96*, 537; 1 Peg B *Obs 107*,1*; 75 Peg *PASP 97*,280*; X Per *ApJ 299*,653*; RW Per *PASP 99*,159; RY Per *AJ 92*, 1168; AW Per *BAAS 19*,710*; AX Per *BAAS 16*,506; DM Per *MN 222*,167*; GK Per *ApJ 300*, 788*; IQ Per *ApJ 295*,569*; β Per *RevMex 10*,257, *PASP 97*,51; Phi Per *ApSpSc 107*, 323; AE Phe *AA 34*,345; AI Phe *ApJ 282*,748*; UV Psc *BAAS 16*,473; VZ Psc *BAAS 17*, 584; AO Psc *PASP 98*,104*; Dzeta Psc B *PASP 96*,179*; Omega Psc *AApSup 61*,363*; RX Pup *MN 208*,161; PV Pup *AAp 132*,219*; U Sge *PASP 97*, 138, *AJ 92*,1168*; V Sge *MN 219*,809, *ApJ 306*,618; WY Sge *ApJ 282*,763*; WZ Sge *ApJ 301*,252*; HM Sge *ApJ 280*, 695, *AAp 139*,296, *142*,85; ∂ Sge *Highlights Astr. 7*,207*; W Sgr *PASP 96*,630; RS Sgr *PASP 98*,1342*; V1223 Sgr *ApJ 289*,300*; V1647 Sgr *AAp 145*,206*; V3885 Sgr *AAp 151*, 157*, *MittAG 62*,281*; Ypsilon Sgr *AAp 166*,237; U Sco *MN 213*,443; V701 Sco *MN 226*, 889*; V760 Sco *AAp 151*,329*; V818 Sco (X-1) *AJ 90*,2077*; Nu Sco, π Sco and Rho Sco *ApJSup 64*,487*; RT Scl *MN 223*,581*; VY Scl *PASP 96*,559*; VZ Scl *MN 225*,43; AL Scl *AAp 179*,141*; RS Sct *MN 209*,645*; RY Sct *Bull Abas 58*,101*; RZ Sct *ApJ 289*,748; W Ser *MittAG 62*,275, *63*,194; RT Ser *PASP 97*,151; EG Ser *PASP 98*,1312*; MR Ser *MN 226*,209*; 39 Ser *PASP 97*,355*; 41 Sex *ApJSup 59*, 229*, *PASP 98*,238*; V471 Tau *BAAS 18*,978, *JRASC 79*,235; V711 Tau *BAAS 16*,473, *AJ 92*,1403, *AAp 160*,73, *176*,267, *Pub. Beijing Obs. 6*,211; σ^1 and 63 Tau *ApJSup 59*, 229*; AQ Tuc *MN 223*, 581*; SU UMa *ApJ 309*,721*; SW UMa *ApJ 308*,765*; UX UMa *AJ 89*,1555*, *PisAZh 11*,617; AN UMa *AZh 63*, 516*; AW UMa *AJ 90*,767*; BE UMa *PASP 97*,328, *ApJ 316*,399; CH UMa *AJ 91*,940*; DN UMa *PASP 98*,1312*; Xi UMa *PASP 99*,38; RR UMi *PASP 98*,650*; γ^2 Vel *AJ 91*,1386*; FO Vir *AJ 91*,1221*; α Vir *AJ 90*,92; VW Vul *AJ 90*,643*; ER Vul *BAAS 16*,473; PU Vul *AJ 91*,563, *ApSpSc 131*,487, *IBVS* 2576; 22 Vul *PASP 97*,725*, *AAp 166*,252; HR 152 *PASP 97*,740*; HR 1023 *PASP 96*,609*; HR 1105 *Obs 104*,224*; HR 1120 *PASP 97*,637*; HR 1878 *JRASC 78*,151*; HR 2214 *ApJSup 59*,229*; HR 2259 *Obs 106*,16*; HR 2692 *PASP 97*,355*; HR 3337 *JRASC 79*,119*; HR 3523 *ApJSup 59*,229*; HR 3725 *PASP 97*,355*; HR 4550 *Obs 104*,192; HR 5053 *Obs 106*,35*; HR 5273 *AJ 93*,683*; HR 6384 *IBVS* 2686; HR 6469 *IBVS* 2937; HR 6902 *JApA 7*, 195*; HR 7038 *PASP 97*,637*; HR 7041 *Obs 107*, 58*; HR 7551 *AAp 139*,123*; HR 7617 *PASP 97*,637*; HR 8708 *ApJSup 59*,229; HD 434 *JRASC 79*,49*; HD 1383 *PubDAO 16*,193*; HD 3950 *ApJSup 61*,419*; HD 7272 *MN 210*,745*; HD 7331 *AAp 178*,114*; HD 8358 *ApJ 297*,691*; HD 9974 *AJ 91*,1392*; HD 11246 *PASP 98*,238*; HD 14346 *Obs 105*,126*; HD 14985 *Obs 105*,201*; HD 16909 *AJ 90*,609*; HD 17198 *Obs 106*,197*; HD 20126 *MN 212*,663*; HD 23838 *AAp 175*,136*; HD 25099 *Obs 105*,29*; HD 25799 *BAAS 18*,985; HD 27935, 28291, 28394, 28634, 29608, 29896 and 30197 *AJ 90*,609*; HD 30869 *AJ 90*,609*, *Obs 106*,13*; HD 37737 *ApJSup 61*,419*; HD 37847 *IBVS* 2669; HD 44172 *ApJSup 61*,419*; HD 44780 *JRASC 80*,91*; HD 46407 *ApJ 268*,264*; HD 47129 *Obs 107*,68*; HD 47755 *AJ 91*,590; HD 52533 *ApJSup 61*,419*; HD 53299A *BAAS 18*,986*; HD 54371 *PASP 97*,355*; HD 55510 *Obs 106*,108*; HD 56429 *AJ 90*,1324*; HD 63099 *PASP 96*,549*; HD 64503 *IBVS* 2242*; HD 65195 and 68874 *MN 212*, 663*; HD 72754 *IBVS* 2949; HD 77581 *ApJ 314*,634*, *317*,746; HD 83065 *Obs 105*,226*; HD 89249 *AAp 177*,105; HD 91948 *IBVS* 2542; HD 94546 *RevMex 11*,143*; HD 96342 *Obs 106*,154*; HD 102010 and HD 102465 *AApSup 57*,99*; HD 102928 *AAp 144*,403*; HD 105982 *JApA 6*,71*; HD 106225 *IBVS* 2543; HD 106760 *JApA 5*,181*; HD 110195 *JApA 6*,159*; HD 112486 *PASP 98*,238*; HD 120710 *AApSup 64*,487*; HD 123058 *MN 211*,793; HD 128220 *MN 226*,249*; HD 137432, 138690, 139160, 139365 *ApJSup 64*,487*; HD 140629 A and B *BAAS 18*,683*; HD 142096, 142165, 142315, 142883 *AApSup 64*,487*; HD 145206 *AAp 144*, 403*; HD 145482 and 145519 *AApSup 64*,487*; HD 145677 *MN 210*,745*; HD 146227 *MN 212*,663*; HD 149162 *ApJ 310*, 354*; HD 149240 *MN 210*,745*, *ApJ 302*,764*; HD 153919 *BAAS 18*,946; HD 158393 *MN 226*,813*; HD 166478 *MN 210*,745*; HD 174853 *IBVS* 2848; HD 176435 *MN 210*,745*; HD 178428 *PASP 97*,355*; HD 182593 *Obs 106*,67*; HD 184728 *AAp 163*,326; HD 191567 *ApJSup 61*,419*; HD 192163 *AAp 149*,337; HD 193793 *ApJ 312*, 807*; HD 194056 *Obs 107*,114*; HD 196795 *AAp 178*,114*; HD 197406 *ApJ 304*,188*;

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HD 210737 *AApSup 62*, 355*; HD 214608 *AAp 178*,114*; HD 214850 *JRASC 79*,167*; HD 218393 *IBVS* 2519; HD 219018 *AAp 178*,114*; HD 219634 *AAp 151*,254*; HD 220057 *ApJSup 61*,419*; HD 224113 *AAp 179*,141*; HDE 245770 *AAp 177*,91*, *BullAbas 58*,282*; HDE 284414, 285766, 285947, 285970, 287116 and J331 *AJ 90*,609*; BD 61°1211 *IBVS* 2669, *AJ 92*,1403; BD 37°444 *PASP 98*,1321*; BD 26°730 *AJ 90*,609*; BD 23°635 *PASP 98*,457; BD 13°3683 *AAp 170*,55*; BD -3°2525 *ApJ 304*,721*; BD -16°6074 *AApSup 69*,397*; CD -31°10727 *ApJSup 64*,487*; CPD -48°1577 *ApJ 292*,601, *ApSpSc 99*,145*, *MN 204*,35P; CPD -58°271 *MN 225*,1005*; W 33436, 60232, 42576, 42574, 12965, 42404, 40480 *ApJ 281*,L41*; Gliese 268 *AJ 92*,1424*; SK 188 *ApJ 292*,511*; G82-23 *ApSpSc 110*,162; M28 V7 *PASP 97*,962; R31 *PASP 96*,811*; R130 *ApJ 309*,714*; LSS 2018 *ApJ 294*,L107*; MS4 (WR29a) *AApSup 58*,117; MWC 560 *BAAS 16*,516; PHL 227 *AAp 149*,L4; PSR 2303+46 *ApJ 294*,L21*; 1502+09 *PASP 97*,41; 0623+71 *PASP 97*,990*; NS 105-67 *ApJ 310*,715*; A 0538 -66 *MN 210*,855, *212*,565, *PASP 97*,418*; A 0620-00 *ApJ 308*,110*; 3A 0729+103 *MN 210*,663, *ApJ289*,300*; 1E 15487+1125 *PASP 97*,1096; 1E 1048.5+5421 *ApJ 314*,641; 1E 1145.1-6141 *PASP 99*,420*; E 1013-477 *ApSpSc 131*,613; E 1114+182 *ApJ 293*,303; E 2003 +225 *MN 221*,823*, *226*,209, *PisAZh 12*,468; EXO 0748-676 *ApJ 306*,599*; H 0139 -68 *PASP 97*,423, *ApJ 286*,328; PG 0834+488 *AJ 91*,940*; 2S 0114+650 *ApJ 299*,839*; 4U 1223 -62 *ApJ 304*,241*, *287*,856*; 4U 1258-61 *MN 221*,961; 4U 1538-52 *ApJ 314*,619*; 4U 1907 +09 *PASJ 38*,463; 4U 1957+11 *ApJ 312*,739*; V 0332+53 *AAp 162*,117.

A number of papers surveying specific characteristics of several members of a group of binaries have not been included in the Table, since the frequent repetition of the same reference would have unduly lengthened it. Studies of RS CVn stars (*AASin 27*,130 and 259; *AApSin 6*,277) and of the rotation of binary stars (*AApSin 6*,154) may be of interest to several readers. Students of cataclysmic variables may be interested in the spectrophotometric study of such objects in *ApJSup 63*,685 and in many more papers in *ApSpSc 130* and *131* than are cited in the Table.

C. POLARIMETRIC STUDIES (A.M. Cherepashchuk)

The most important results are: spectroscopic and polarimetric investigations of the runaway WN7 star HD197406 - a possible binary with an X-ray quiet black hole (Drissen *et al. ApJ 304*,188); polarimetric investigations of ϵ Aur (Kemp *et al. ApJ 300*,L11); circular spectropolarimetry of VV Pup (Wickramasinghe *et al. MN 210*,37); calculations of polarization of intrinsic radiation of tidally distorted stars (Bochkarev and Karitskaya, *ApSpSc 109*,1); calculation of angular distribution and polarization of X-ray burster radiation (Lapidus and Sunyaev *MN 217*,291).

Other publications are: *RevMex 10*,267, *AAp 142*,333, *MN 212*,709, *MN 215*,83, *MN 218*,201, *ApSpSc 118*,291, *ApJ 301*,881, *RevMex 12*,332, *AAp 162*,99, *RevMex 12*,407, *MN 220*,663, *ApJ 306*,215, *MN 222*,225, *Mitt AG 67*,310, *ApSpSc 131*,657, *AAp 130*,197, *PASP 99*,62, *AdvSpRes 3*,265, *AZh 63*,71, *Bull Abas 58*,273, *Astrofizika 23*,503, *IzvKrym 75*,120, *AZh Letters 11*,623, *CommAp 12*,1, and papers in conference proceedings.

D. X-RAY OBSERVATIONS (Y. Kondo)

During the present reporting period two X-ray satellites were in operation. The European satellite EXOSAT, which was launched in May 1983, ended its productive operation in April 1986. The Japanese satellite *Ginga* (galaxy), which was launched in February 1987, was operating successfully as of the closing date of this report. The American satellite *Einstein* (HEAO-2) ended its operation in June 1981. In view of its ongoing archival research program, we will also describe it briefly.

Einstein

The archival data include about 100 binaries with compact objects, about 100 cataclysmic variables, about 80 "ordinary" binaries, and about 60 RS CVn objects.

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The X-ray data are mostly spectroscopic and are in the spectral range 0.3-3.0 keV. A complete listing of all the objects observed with the *Einstein* can be found in the booklet *A listing of All Targets Observed by the Einstein Observatory*, which is available from: Dr. Frederick D. Seward, Head, Einstein Guest Observer Program, Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, U.S.A. He can also provide information about the *Einstein* archival data research program.

EXOSAT

All the objects observed with EXOSAT, numbering 2000, are listed in *The EXOSAT Observing Log*. The catalogue contains hundreds of binary objects. Among the X-ray binaries listed are: SMC X-1, LMC X-1, 2, 3, 4, 6, Cen X-3, Cir X-1, Her X-1, AM Her, Cyg X-1, 2, 3, and Vela X-1. A number of cataclysmic variables, such as U Gem, SS Cyg and WZ Sge, have also been observed. Among the "ordinary" binaries observed are Algol and W UMa. Information concerning the use of the EXOSAT archival data may be obtained from: Dr. N. E. White, EXOSAT Project Scientist, ESTEC-ESA, Postbus 299, Noordwijk, The Netherlands.

Ginga

The primary objective of the *Ginga* is to observe variabilities in X-ray sources. As of the time of the preparation of this report, Algol and UX Ari have been observed. Compact X-ray sources observed include X 0540-693, 1E 2259+586, SMC X-1, GX 1+4, GX 3+1, NGC 6624, X 1916-056, GC Transient, GX 5-1, Cyg X-2, LMC X-1, LMC X-2, SS 433 and MX 1353-645, some of which are known binary systems. The project scientist for *Ginga* is Dr. F. Makino, Institute of Space and Astronautical Science, 4-6-1 Komaba, Meguro-ku, Tokyo 153, Japan.

E. ULTRAVIOLET OBSERVATIONS (B.J.M. Hassall)

Results from the satellite, the International Ultraviolet Explorer (IUE), continue to dominate the literature for the wavelength range 1200-3200Å. Close binaries comprise a large fraction of this work; of the 61966 IUE observations obtained by 1 June 1987, 1324 exposures are of symbiotic stars, 1167 of dwarf novae, 880 of classical novae and 960 of X-ray binaries alone. The maturity of IUE is illustrated by the publication of the book *Exploring the Universe with the IUE Satellite* which reviews the advances in UV astronomy over the last ten years. Chapters on symbiotic stars (Nussbaumer and Stencel), novae (Starrfield and Snijders), cataclysmic variables and X-ray binaries (Cordova and Howarth), interacting binaries (McCluskey and Sahade), Wolf-Rayet stars (Willis and Garmany) and supergiant eclipsing systems (Hack and Stickland), cover their respective topics in greater depth than the limited space here allows.

Further UV observations of close binaries are reported in the three proceedings of IUE symposia published during the triennium, namely: NASA CP2349 (1984), ESA SP218 (1984) and ESA SP263 (1986). Proceedings of conferences devoted specifically to interacting binaries also include contributions on UV observations: *Interacting Binaries*, Reidel, 1985, Eds. Eggleton and Pringle; *Recent Results on Cataclysmic Variables*, 1985, Bamberg, ESA SP236; *Cataclysmic Variables*, *ApSpSc 130* and *131*. Of the other recent UV satellites, Copernicus, ANS and Voyager, the last is currently the most important with regard to observational papers. The paragraphs below address each of the major groups of close binaries, listing the more important UV references for each.

IUE observations of recent nova outbursts have confirmed the existence of the class of neon novae in which a TNR outburst on a ONeMg white dwarf leads to enrichment of Ne and Mg in the ejecta. The signature in the UV is provided by strong lines of [NeIV] 1602,2426 and [NeV] 3346. Thus V1500 Cyg is joined by V693 CrA 1981 (Williams *et al. MN 212*,753) with Z≈0.4, V1370 Aql 1982 (Snijders *et al. MN 211*,7p) and N Vul 1985 No.2 (Starrfield *et al. ApJ 303*,L5). The 1985 outburst

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spectra of RS Oph revealed strong coronal lines of FeXI, FeXII and FeXIII, the first to be observed in a recurrent nova in the UV (Snijders in Proc. Manchester Conf.: *RS Oph and the Recurrent Nova Phenomenon*, Ed. Bode, p.51). They are presumed to originate in shocked gas where the nova shell meets the companion's stellar wind. The ejecta abundance appears to be compatible with TNR rather than an accretion event.

Long term IUE monitoring of several symbiotics has been undertaken, in some cases giving direct support for binarity. Fernandez-Castro *et al.* (ESA *SP236*,225) observed the prototype Z And in both outburst and quiescent phases, and attribute quiescent variability to orbital motions with a period of 760 days. Periodic photometric variations and wavelength shifts in the UV emission lines in HBV 475 led Mueller *et al.* and Nussbaumer *et al.* to a binary interpretation (*AAp 154*,313; *AAp 169*,154). A similar conclusion was reached by Viotti *et al.* (*ApJ 283*,226) for the high velocity symbiotic AG Dra. Other observations of symbiotics are reported in *BAAS 17*,886 (Voyager data of AG Peg); *MN 212*,939; *AAp 140*,317 and *AAp 161*,287.

During the principal eclipse of Algol-type systems (Plavec *et al.* NASA *CP 2349*,420) the existence of a high temperature region and the so-called SiIV/CIV flux reversal has been demonstrated. Peters and Polidan (*ApJ 283*,745) identify the source as a high temperature accretion region (HTAR) where the accretion stream impacts directly on the stellar surface, although differences in line profiles between ion species imply more than one region may be involved (Sahade and Hernandez *RevMex 10*,257). Plavec and Dobias continue their series on this group (e.g. *PASP 99*,159 and 274; *AJ 92*,171 and 440).

Ruciński (*MN 215*,615) finds that the chromospheric MgII line flux of W UMa stars, while independent of orbital phase, may be stronger at lower effective temperatures. This relation is extended to RS CVn systems by Fernandez-Figueroa *et al.* (*AAp 169*,237). Conversely, the transition region lines in W UMa's behave the same as in single stars (Oranje *AAp 154*,185). Further rotational effects in RS CVn's are investigated by Vilhu and Heise (*ApJ 311*,937) and the Armagh group and co-workers (*AAp 180*,172 and refs. therein).

Two dwarf novae monitored during quiescence (VW Hyi, Verbunt *et al. MN 225*,113, WX Hyi, Hassall *et al. MN 216*,353) undergo a secular decrease in UV luminosity between outbursts. This is more easily accommodated within a mass transfer burst model than a disc instability, unless the source of the UV luminosity is a cooling white dwarf rather than the accretion disc. Extreme UV (Voyager) observations of a superoutburst of VW Hyi (Polidan and Holberg *MN 225*,131) show that the fading between precursor and outburst proper is more marked than at optical or IUE wavelengths. Otherwise, the precursor closely resembles an ordinary outburst in the extreme UV. Phase resolved studies of line profiles indicating a wind are reported for RW Tri and DQ Her (Cordova and Mason *ApJ 290*,671), for OY Car in superoutburst (Hassall *et al. ApSpSc 130*,371) and for Z Cam (Szkody and Mateo *ApJ 301*,286). Observations of several other CV's are reported in *AJ 90*,9; *MN 210*,197; *MN 212*,231; *MN 212*,645.

The UV flux of the "3-period" intermediate polar TV Col was observed to be modulated on the orbital period of 5.5h, which Bonnet-Bidaut *et al.* (*AAp 143*,313) associate with an X-ray illuminated bulge on the accretion disc. Mateo *et al.* (*ApJ 288*,292) also detect the 4-day period. Other magnetic CV's are reported in *ApJ 293*,321 and *ApJ 315*,L123 and references therein.

McClintock *et al.* (*ApJ 283*,794) argued from a reddening study that the distance to Cyg X-2 is greater than 1.1kpc and hence that the degenerate object is indeed a neutron star in this LMXB. High resolution spectroscopy of the high mass X-ray binaries Vela X-1 and SMC X-1 show substantial variations with orbital phase of the P Cygni profiles (Hammerschlag-Hensberge *et al. ApJ 283*,249; Sadakane *et*

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al. ApJ 288,284), in general agreement with the models by McCray *et al. (ApJ 282*, 245) for a strong stellar wind interacting with the X-ray source. Other early-type X-ray binary observations are reported in *ApSpSc 109*,175; *AAp 141*,279; *MN 225*,985.

Observations of atmospheric eclipses in supergiant systems are reported for ε Aur (Ferluga and Hack *AAp 144*,395) which has no completed its 1982-84 eclipse. A series of papers by the Hamburg group (*AAp 138*,333; *AAp 147*,103; *AAp 156*,172; *AAp 170*,70) investigate the wind in Dzeta Aur and its relatives 31 Cyg and 32 Cyg. The new member of the class 22 Vul, with the shortest binary period, has been much studied. The fact that the B star is permanently embedded in the dense wind of its G companion, leads to a much hotter (300,000K) electron temperature than in the longer period systems (Ake *et al. ApJ 298*,772; Reimers and Che-Bohnenstengel *AAp 166*,252).

Papers relating to binary aspects of Wolf-Rayet stars concentrate on the search for compact companions and what change, if any, binarity imposes on the wind structure (e.g. *ApJ 296*,222; *ApJ 313*,358; *AAp 146*,307).

3. Derived Physical Data

A. ABSOLUTE DIMENSIONS AND APSIDAL MOTION (D.M. Popper)

Observational Results on Absolute Dimensions

There appear to have been no reviews of absolute dimensions of close binaries within the three-year period. New determinations of masses and radii, based on observations leading to new spectroscopic or photometric orbits or both have been obtained for the following detached systems. Only results of good accuracy are listed here. HS Aur *AJ 91*,383; GZ CMa *AJ 90*,1324; PV Cas *AJ 93*,672; WX Cep *AJ 93*,672; AH Cep *MN 223*,513; V1143 Cyg *AAp 174*,107; V624 Her *AJ 89*,1057; FL Lyr *AJ 91*,383; TZ Men *AAp 175*,60; EW Ori *AJ 91*,383; V451 Oph *AAp 167*,287, *ApSpSc 106*,93; IQ Per *ApJ 295*,569; LX Per *ApSpSc 112*,273; AI Phe *ApJ 282*,748; V1647 Sgr *AAp 145*,206; V760 Sco *AAp 151*,329; AL Scl *AAp 179*,141; DM Vir *AAp 137*,281.

New determinations for semi-detached systems are: TT Aur *AAp 162*,62; S Cnc *ApJ 285*,208; R CMa *ApJ 297*,250; HH Car *RevMex 11*,99; YY Cet *MN 218*,159; RY Gem *AJ 92*,440; u Her *MN 211*,943; while W UMa systems with newly determined masses and radii are: XY Boo *ApSpSc 107*,347; BV Dra *AJ 92*,666; BW Dra *AJ 92*,666; and XY Leo *ApJ 290*,696. Standards of accuracy for systems in these two categories are lower than for detached systems.

Masses and luminosities have been obtained by combining spectrographic and interferometer observations for α Aur (*AJ 90*,1503) and Chi Dra (*AJ 93*,1236).

Techniques

Techniques for spectroscopic observations and for their analysis continue to develop. While most of the results listed here are based on photographic spectrograms, an increasing proportion is employing linear digital detectors of considerably greater sensitivity and lower noise (Reticons, CCD's). Radial velocity spectrometers are starting to be employed in this endeavor, although the relatively large rotational velocities in most eclipsing binaries are an obstacle for this kind of observation. For photographic observations, as well as those using the newer types of detectors, cross-correlation techniques are being used increasingly, with the scheme developed at Victoria (*PubDAO 16*,159) receiving considerable application for the analysis of photographic plates. The method has the potential of detecting and measuring velocities of components not amenable to more conventional techniques and thus of providing results for stars of classes not heretofore available. Examples are the evolved early B stars HR 7551 (B0.5Ib, *AAp*

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132,123) and V380 Cyg (B1.5 II-III, *AAp 141*,39). The feature due to the secondary in the cross-correlation function in each of these systems is very poorly defined, and troublesome systematic effects are present. Further studies are required (e.g. high resolution, high S/N profiles) in order to test the reliability of this type of analysis. The same comment holds for any of the newer techniques, particularly in cases where the pertinent details of the spectrum are not displayed directly. An example of a particularly thorough test of cross-correlation results is that for the W UMa system XY Leo (*ApJ 285*,683).

Some Noteworthy Results

The early B systems V348 Car (*MN 213*,75) and V1182 Aql (*MN 225*,961), though not yet definitive enough for the list of detached systems given above, have the potential of replacing LY Aur as the most massive system with directly determined masses. The secondary of EK Cep, mass 1.12M⊙, is found to be in a state of pre-main sequence contraction (*ApJ 313*,L81), unique among stars with well established properties. A light curve of HD 27130, the eclipsing binary in the Hyades cluster, has been obtained and analyzed (*AJ 93*,1471) to accompany the earlier double-lined spectrographic orbits. It is a matter of judgment whether the results for this important system are better employed for refining the distance to the Hyades, as in the cited reference, or to serve as a direct test of interior models (*ApJ 307*, L61), the distance being assumed known.

During the period of this report, noteworthy progress was made for the first time in extending our knowledge of fundamental properties down the main sequence to stars less massive than the sun. In addition to HS Aur, FL Lyr, and EW Ori, listed under "observational results", systems with less definitive results are α CrB (*AJ 91*,428) and CG Cyg (*AJ 90*,761). The former is particularly noteworthy for the orbit of the secondary, which is approximately 5 mag fainter than the primary, its detection and measurement being an accomplishment with the McDonald Reticon.

One use made of absolute dimensions is, by comparison with interior models, to deduce the age and chemical composition of a "best" model. In some cases, the He abundances so deduced have been at variance with abundances (about 0.24 to 0.30 by mass fraction, Y) generally considered to prevail on the basis of spectrographic evidence of various kinds. Examples of unusually low He abundances (Y≈0.18) are for IQ Per (*ApJ 295*,269) and DM Vir (*AAp 137*,281). In such cases, with excellent observational results, it may be prudent to call into question the models employed in the comparisons. Another example is the system AI Phe. The more massive component (1.2M⊙) is well evolved into the Hertzsprung gap. Comparisons with models (*ApJ 291*,270) yield Y≈0.38, an exceptionally large value. But preliminary revised velocities (unpublished), increasing the velocity amplitudes by only a few km s^{-1}, bring Y to 0.34, and it remains to be seen what the outcome of a definitive study will be.

Another interesting and important case is Chi Dra, a binary studied by speckle interferometry (*AJ 93*,1236). Earlier work had led to the conclusion that the primary had a mass of only 0.88M⊙, unprecedentedly low for an F7 star. Small revision in the radial velocity of the secondary (*AJ 93*,1236) increases the mass to 1.03M⊙, an excellent example of the care with which radial velocities must be obtained in order to avoid improper results. Even this mass is low for the luminosity, leading to the conclusion that the star is well evolved, with a system age ≈ 8×10^9y, an almost unique case of an old disk star ([Fe/H] ≈ -0.3), appreciably older than the sun, with well determined fundamental properties.

Finally, we note two contributions by R. and R. Griffen, based on results from their radial velocity spectrometer. *JRASC 80*,91 contains a review of the current position with respect to masses of cool giants. The preponderance of

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masses well above 2.0M⊙ is strengthened. In *JApA 7*,195 they discuss a new program for radial velocities of systems with composite spectra, the results from which could increase our meager information on masses of evolved stars.

Apsidal Motion

New results of high quality on apsidal motion are for EK Cep (*AJ 90*,358) and V1143 Cyg (*AJ 90*,348, *AAp 174*,107). Both show good agreement with the predictions of generally accepted gravitational theory. The results for EK Cep (see also *ApJ 297*,405) may provide the best example to date for agreement between theory and observation for a case in which the general relativistic and Newtonian contributions are comparable. On the other hand, the agreement in the case of AS Cam (*BAAS 19*,578), for which the Newtonian contribution is dominant, is very poor, the observed motion being only about 40% of the predicted Newtonian and 30% of the predicted total motion. This disagreement is of a much different nature from that in the much-discussed case of DI Her, where the relativistic term should dominate, and both the Newtonian and the observed values are vanishingly small. Suggested effects not considered in the standard theory (spin-orbit coupling with the rotational and orbital axes at large angles to each other - Shakura *SovAstrLett 11*, 244; viscosity - Hosokawa *ApSpSc 115*,403) would appear inadequate to explain the discrepancies.

B. PROXIMITY EFFECTS AND LIMB DARKENING (M. Kitamura)

The reflection effect for gray and nongray atmospheres has been investigated in detail by several workers with application to close binary systems. Of these, Vaz and Nordlund (*AAp 147*,281) studied the effect for gray atmospheres with convection and for the particular case of Algol they showed that the theory is in good agreement with observation. A critical review on the treatment for the reflection effect of eclipsing binaries was also presented by Vaz (*ApSpSc 113*,349). Yamasaki (*PASJ 38*,449) carried out a detailed numerical calculation for the reflection effect on nongray, plane-parallel, LTE, radiative equilibrium atmospheres with application to a model close binary consisting of early-type components and obtained rigorous values of monochromatic albedo.

The gravity-darkening of highly distorted stars in close binary systems has been studied as series work by Kitamura and Nakamura (*AnnTokyo 21*,229, 311 and 387). They showed that for main-sequence components in detached systems the empirical values of the gravity-darkening exponent are almost unity for O9.5 to early A and 0.35±0.03 for late A down to G1, while for normal giants in detached systems the corresponding empirical values are found to agree with the ones expected from model atmospheres. Most conspicuous result would be for secondary components filling the Roche lobe in semi-detached systems in which the empirical values of the exponent are found to be significantly greater than unity. In order to explain such observational evidence of excessive gravity-darkening, an additional darkening by mass loss in semi-detached systems has been studied by Unno *et al.* (*IAUColl 108*).

Non-linear limb-darkening laws have been studied by Rubashevskij (*Astrometr.Astrofiz. 51*,23 and 28, *52*,18) with two parameter representation; he also presented new values of theoretical limb-darkening for application to classical eclipsing binaries (*ATs* 1275,1297,1299). Another study on non-linear limb-darkening laws for detached systems was made by Goncharskij *et al.* (*AZh 63*,725).

4. Structure and Models of Close Binaries

A. EARLY TYPE SYSTEMS (K.-C. Leung)

Early type contact binaries come in two different varieties: evolved contact and zero-age contact systems. So far, the number of the evolved systems discovered has far exceeded the number of zero-age systems, of which very few are known,

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among them V701 Sco and BH Cen and, possibly, TU Mus, PZ Pyx and AW Lac. It is of vital interest for our understanding of binary formation and for the modeling of the structure of contact systems that these systems be studied. Their mass ratios are very important for testing the current theories of the structure of zero-age early type contact systems. Some progress has been made in the past three years. Bell and Malcolm (*MN 226*,399) obtained good phase coverage radial velocity curves as well as new light curves of V701 Sco. Their results confirmed the earlier result (with only a few spectra) reported on this system. There is excellent agreement between the spectroscopic and photometric mass ratios, both being essentially unity. The same authors (*MN 227*,481) also secured spectroscopic and photometric observations of the suspected (from period and spectral relation) zero-age contact system RZ Pyx. Again, there is good agreement between the spectroscopic and photometric mass ratio, 0.82. Unfortunately, the long awaited spectroscopic result for BH Cen is still not available (a photometric mass ratio of 0.84 having been reported earlier). TU Mus, with a mass ratio of 0.72, may be a marginal zero-age system (Leung, *Beijing Coll.*). Spectroscopic work is urgently needed for BH Cen and AW Lac (a photometric mass ratio of unity having been reported in an earlier study). Evidently, the mass ratios for early-type zero-age systems are not limited to unity.

If we accept the standard view of close binary evolution, we expect the mass gainer in semi-detached binaries to evolve toward asynchronous rotation due to the rapid accretion of mass and momentum. In some cases, the gainers may reach critical rotation while the losers are in contact with their standard critical potential surfaces. These systems were named double contact binaries by R.E. Wilson. Investigations of this phase of close binary evolution are important to our understanding of rapid phase of mass transfer. Wilson *et al.* (*ApJ 289*,748) reported another system of this type, RZ Sct. It is recommended to spectroscopists that radial velocity studies of the Rossiter effect are very much needed for the study of asynchronous rotation and for the investigation of truly double contact systems.

At present, there are about 15 early-type contact systems with spectral types B or earlier reported in the literature. Some of them present severe challenges in interpretation and may require multi-dimensional approaches. For example, the research group at the Abastumani Astrophysical Observatory (Cherepashchuk, Babaev, Kumsiashvili, Karetnikov and Skul'skij) tackled RY Sct by means of spectrophotometry, optical, intermediate band-pass photometry, emission at Hα and radio observations. Other systems could well deserve similar approaches. The systematic spectroscopic and photometric observational program on early-type systems by Bell, Hilditch, Adamson and Malcolm at St.Andrews is particularly noteworthy. This effort will help to build a good data base for absolute dimensions of early-type systems, reliable temperatures for their components and more accurate locations in the conventional H-R diagram. Such work is very useful for the study of close binary evolution.

Among early-type binaries, some consist of one component with spectral type A and a companion of later spectral type. Their light curves are similar to that of β Lyr, i.e. with large differences between the depths of eclipses (primary and secondary). The polar temperature differences between components are huge, typically several thousands of degrees. Their photometric solutions indicate contact configurations. Many systems with modern Roche lobe light curve analyses indicating contact configurations have appeared in the literature. How can the huge jump (or drop) in temperature be maintained at the interface of such a contact binary? Usually, we would expect A stars to have radiative atmospheres and late-type stars to have convective atmospheres. There does not seem to be any debate about two early-type stars forming an early-type contact and two late-type stars forming a W UMa system. Can we form a mixed-type contact system with a large temperature difference? Are the published (contact) solutions incorrect?

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B. ALGOLS (M. Plavec)

The term "Algols" is becoming a convenient and fairly accurate synonym for "detached binary systems with non-degenerate components". The once contemplated subgroup with "undersize subgiants" consisted partly of stars now included among RS CVn systems, and partly of inadequately observed semi-detached systems; the demise of the latter group, advocated by Hall, is further supported by a more recent statistics by Budding (*PASP 97*,594). The status of our knowledge on Algols, current trends in the field, and main problems have been very nicely reviewed by Budding (*ApSpSc 118*,241). He also formulated the importance of studying the Algols: Among the eclipsing binaries, this is the most populous type; they are relatively easy to observe, and their fundamental parameters can be established with fair accuracy; and they represent a crucial link between the virtually non-interacting detached binary systems and the generally much more complex interacting binaries of advanced age (usually containing compact components). I wish to add that some phenomena associated with "interaction", i.e. with the process of mass transfer between the components and mass loss from the system, are present in the "classical Algols", albeit on a diminished scale; but just this circumstance makes it useful to study some aspects of the processes on Algols. The position of the Algols in the grand evolutionary scheme of interacting close binaries is best seen if you read the comprehensive treatment by Iben and Tutukov (*ApJSup 58*,661; *ApJ 313*,727), or the overview by Iben (*QJRAS 26*,1). The possible post-Algol evolution was also discussed by de Loore (*ApSpSc 99*,199).

Budding compiled a catalog of 414 Algols and possible Algols (*Bull.d'Inform.* No.27, ed. C. Jaschek). Together with the earlier statistics by Giuricin *et al.* (*ApJSup 46*,1; *ApJSup 52*,35; *AApSup 45*,85), this is a rich source of statistical information, and good reference for further studies. However, the material is of necessity of very inhomogeneous quality and reliability. The creation of a much shorter but homogeneous list of well-determined parameters will eventually result from the efforts of many people; a good standard is set e.g. by Etzel and Olson (S Cnc: *AJ 80*,504) and by Etzel's work on TT Hya. Plavec and Dobias (*AJ 93*,171 and 140; *PASP 99*,159 and 274; Plavec, 10th ERC-IAU, Prague) find from the IUE spectra that the Algols usually classified as A1-A5 are quite often late B stars, the optical spectra being contaminated by shell lines and optical photometry being at times affected by an incomplete subtraction of the flux of the secondary component. An opposite phenomenon was found for the B5 primary in RY Per, whose spectrum resembles a B9 star. This star is very rapidly rotating (Van Hamme and Wilson *AJ 92*,1168) and has a circumstellar shell. If the latter is the cause of the discrepancy, then RY Per is similar to the non-eclipsing interacting binary KX And, for which Štefl (*BAC 36*,313) demonstrated the presence of an optically thick shell in the UV. Thus, caution is needed in evaluating the statistics, and for comparison with theory, it is often better to deal with individual cases.

A systematic effort at comparing the theoretical models with actually observed Algols is under way in Brussels. De Greve (*SpScRev 43*,139) presented a thorough review of the current status of theoretical modeling of the evolution of Algols, based on the very extensive work done by him and the entire, very active group headed by de Loore in Brussels. The most recent novelty introduced in the modeling is the inclusion of the convective overshooting of the core; De Greve finds that it makes the end masses larger and increases the probability of the occurrence of case A of mass transfer. Case B remains the most usual case for Algols, though. De Greve finds once again that observed systems can be matched only if significant loss of mass and of angular momentum from the evolving systems is postulated.

These loses presumably occur mainly during the rapid phase of mass transfer, therefore the search for such systems continues. The accompanying presence of large and dense structures of circumstellar and circumbinary matter seriously complicates the analysis of such systems, but also calls attention to them. The prob-

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lems associated with studying these complex systems (called W Serpentis stars by Plavec) have been discussed by Plavec (in Eggleton and Pringle: *Interacting Binaries*, p.155) and, from a different point of view, by Sahade and McCluskey (in Kondo: *Ultraviolet Astronomy with the IUE*), and by Sahade (in *New Insights in Astrophysics*, p.267). Foremost among them is β Lyrae, reviewed comprehensively by Sahade (*SpScRev 26*,349). Plavec (10th ERC-IAU, Prague) finds, from a combination of optical and IUE spectra, that the secondary star definitely has a flux distribution typical for an accretion disk, while the primary is also anomalous; in the optical, it can be reasonably well fitted by a model atmosphere at T_{eff} = 13,000 K, log g = 2.5, but with respect to any model hotter than 11,500 K, its far UV flux is too low. The above specification of parameters of the primary star in the optical region comes from the work by Balachandran *et al.* (*MN 219*,479), who found from spectral synthesis of the line profiles that the surface material in the primary star of β Lyr underwent the CNO-cycle processing and is enriched in He and N, and underabundant in H, C, and O. Indications of the same abundance anomalies have been found in Lambda Tau and β Per by Cugier and Hardorp (*BAAS 17*,553).

Although it is tempting to find and understand a system near the phase of rapid mass transfer, it shows that ordinary Algols display similar phenomena, on a milder scale, but easier to analyze. Thus the emission lines found in the Serpentids can also be seen in the Algols, provided they are observed at or near the total eclipse of the primary component. Systematic search by Plavec (10th ERC-IAU, Prague) netted 10 systems with emission lines. Absolute and relative intensities of the super-ionized emission lines differ; in particular, early-type systems (V356 *Sgr*, RY *Per*) *tend to display* NV *much stronger than* CIV, *while in systems* near A0 (TT Hya, RS Cep), the opposite is true. Interesting information about electron temperatures and chemical composition can be extracted from such data, following the pioneering work by Peters and Polidan (*ApJ 283*,745). The problem of the energy source and location of this super-ionized plasma is related to the general problem of the geometry and physics of the circumstellar structures in Algols. Do genuine accretion disks exist in Algols? Are they optically thin or thick?

The problem of the circumstellar structures is being attacked from several directions. Observationally, Kaitchuck *et al.* (*PASP 97*,1178) continued their search for semi-permanent and transient disks in Algols, using fast spectrophotometry of the Hα line. More oriented towards detecting structure emitting in the continua is the systematic work by Olson (in Eggleton and Pringle: *Interacting Binaries*, p.155). Another approach is to attempt to solve the light curves of more complicated systems by including the effects of a disk; this has been done by Wilson for several objects (e.g. for RW Per, subm. to *PASP*), by Pavlovski and Kříž for SX Cas (*BAC 36*,153), by Pustylnik and Einasto (*ApSpSc 105*,259) for a circumbinary envelope in AO Cas and RY Gem. Another approach is to study theoretically the interaction between the mass transferring stream, the disk, and the accreting star. Among these studies, let me mention the two-dimensional hydrodynamical *treatment that reveals the presence of spiral shocks*, by Sawada *et al.* (*MN 219*, 75), and the three-dimensional study by Hadrava (*BAC 35*,335).

An important part of the problem is the interaction between the rotation of the accreting star and the impacting stream. Wilson and collaborators repeatedly point out the probable existence of "double-contact binaries", in which the accreting star spins so fast that it has filled its critical tidal lobe and cannot accept any more matter (Van Hamme and Wilson *AJ 92*,1168 and references therein).

Another useful approach to the problems of Algols is to realize that they are related in many ways to other types of binary stars. The connection to the RS CVn stars has been pointed out by Olson (*IAPPP 19*,6) who started a search for spots on the cooler components. Another close relation exists between Algols and Be stars, and was stressed by Harmanec, Plavec, etc. (in Slettebak and Snow: *Phy-*

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sics of Be Stars). The third and perhaps most important connection is to cataclysmic variables, with which the Algols share the accretion processes, circumstellar structures, and super-ionized UV lines. This connection is systematically studied by Polidan (10th ERC-IAU, Prague). Polidan also uses his own observations with the Voyager spectrometer, which extend the spectral coverage down to 912Å.

C. W UMA SYSTEMS (K.-C. Leung)

For more than a decade since the development of the Roche model for light curve analysis we have been able to derive relatively reliable photometric solutions for close binary systems. These methods, developed by many authors, introduce a new parameter, the mass ratio, to our photometric solutions. This is an important parameter, since it enables us to calculate absolute dimensions for single-lined spectroscopic binaries. The potential for gaining a much larger set of fundamental astrophysical quantities (e.g. mass and radius) is enormous. However, in practice, reality has proven to be not as rosy as we had hoped. As more modern photometric solutions are published, we find that there are irreconcilable differences between the spectroscopic and newly obtained photometric mass ratios in a considerable number of close binary systems. There are doubts in the minds of many astronomers, especially among the spectroscopists, about the reliability of the photometric values.

There have been three independent studies, by Kałużny (*AA 35*,313), Maceroni *et al.* (*MN 217*,843) and Leung (*Beijing Coll.*), using very different criteria in compiling data from the literature, to compare the mass ratios from spectroscopy and photometry. All of these investigations conclude that there is good agreement between accurate spectroscopic results (especially from cross correlation methods) and modern photometric mass ratios (where well-determined) for both A and W type W UMa systems. No matter how well things fit together, however, there always seems to be an exception to the rule. Maceroni (*AAp 170*,43) found that for V523 Cas the mass ratio determined by the cross correlation method differed significantly from the photometric value. He attempted many numerical variations on the light analysis but still could not account for the discrepancy. We wonder if the photometrists and spectroscopists should re-examine this system.

One of the outstanding problems in late-type contact binaries is the relation/difference between A and W type systems. Kilmartin *et al.* (*ApJ 319*,334) found V677 Cen most unusual, classifiable either as an A or W type system. Further investigation of this system may be of great interest to the connection between these two types of W UMa binaries.

Asymmetry in light curves (O'Connell effect) has been a major problem for the photometrists. Its astrophysical meaning is still a great mystery. Milone *et al.* (*ApJ 319*,325) interpreted this effect in terms of starspots on the contact system RW Com. This was the first attempt to include spot parameters into the Wilson-Devinney computing codes.

The importance of studying eclipsing systems in star clusters has been reemphasized by Baliunas and Guinan (*ApJ 294*,207) and Kałużny and Shara (*ApJ 314*, 585) in their papers on W UMa systems in NGC 188. Work on this cluster is of great importance to the evolution of close binaries since it contains so many systems.

The St.Andrews group (Hilditch, McFarland and King) continue to observe and publish spectroscopic and photometric results on many W UMa systems. They have also tried to determine the absolute temperatures of the components. There is no doubt that their continued effort will make great contributions to the accumulation of basic uniform astrophysical quantities for the late-type contact and near-contact binaries. These data will be important for modeling late-type systems and testing the reliability of spectroscopic and photometric mass ratios. Of course, there are many individuals and groups around the world who continue excellent work

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on these systems also. If this trend of activity continues, there is hope that we may have a better understanding of the nature of A and W types by the time of the next Commission report.

Unfortunately, we cannot describe the situation for long-period contact or near-contact binary stars as optimistically as we did for W UMa systems. There are many reasons for the general reluctance to observe long or very long period systems, but these stars are just as important as the short period systems as far as our study of the total picture of binary evolution is concerned. In order to study Case B or Case C mass transfer systems we must look to longer periods. There are systems which have light curves very similar to those of W UMa and β Lyr stars with spectral types of F and K, but with periods ranging from about one hundred to several hundred days. Li and Leung (*Highlights of Astron. 7*,217) reported that three of these systems, 5 Cet, PW Pup and HD104901B, are contact or near-contact systems. Clearly, these binaries must be the result of Case B mass transfer. The light curve of UU Cnc reported by Nha *et al.* (*Korean J.Astron.Sp.Sci. 3*,1) is very similar to that of 5 Cet (both systems have periods of about 96 days). It is believed that the components of these systems are supergiants or giants. We hope that observers will take new interest in longer period systems.

D. CATACLYSMIC VARIABLES

Review articles covering different aspects of CV's can be found in conference proceedings. Other publications include *Catalogues* by Duerbeck (*SpScRev 45*,1) and Ritter (*AApSup 57*,385). Below we shall discuss only some of the highlights; reader is also referred to Sections 2 and 6 of this Report.

CV's are being vigorously observed in the X-ray, UV, optical and IR parts of the spectrum. An attempt to detect the EUV (<912Å) flux from CV's turned unsuccessful (Polidan and Carone *ApSpSc 130*,235). On the other hand the study of their radio-emission becomes an important topic (Chanmugan *ApSpSc 130*,53). The targets of observing programs are both new objects which have previously been unobserved in a given spectral region and selected individual systems of particular importance. For example, VW Hyi was observed in a broad range of wavelengths, from X-ray (EXOSAT), through UV (Voyager and IUE), to the visual (*MN 225*,73 and ff.). Of particular value are observations of dwarf novae throughout their outburst cycles. Photometry of Z Cha (Cook *MN 216*,219) revealed that the disk radius increased during outburst by 40%; there was also a change in the shape of the white dwarf eclipse which can be interpreted as being either due to variable, non-uniform surface brightness distribution of the white dwarf (Smak *AA 36*,211) or due to variable optical thickness of the inner parts of the disk (Wood *MN* in press). Photometry during eclipses is being used for mapping of the surface brightness distribution on the accretion disk (e.g. Horne *MN 213*,129; Horne and Stiening *MN 216*,933; Warner and Donoghue *MN 224*,733; Włodarczyk *AA 36*,395). Mapping of the disk in the emission lines also becomes increasingly important (Marsh and Horne *ApSpSc 130*,85).

Irradiation of the secondary by the boundary layer and/or the white dwarf is becoming an important topic. Observational evidence is available for Z Cha (Wade and Horne *ApJ* in press) and SS Cyg (Hessman *et al. ApJ 286*,747, Robinson *ApSpSc 130*,113), where enhanced irradiation during outbursts apparently leads to an increased mass outflow (Hessman *ApJ 300*,794). Variable irradiation is important in many types of systems, including SU UMa (Osaki *AAp 144*,369), novae (Shara *et al. ApJ 311*,163; Kovetz *et al. ApJ* in press), soft X-ray transients (Hameury *et al. AAp 162*,71) and magnetic CV's with high and low states (King and Lasota *AAp 140*,L16).

Warner (*MN 227*,23) re-determined absolute magnitudes of CV's and discussed several important relations for dwarf novae, involving orbital periods and parameters of the outburst cycles. There have also been new statistical studies of dwarf

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nova light curves (Szkody and Mattei *PASP 96*,988; Gicger *AA* in press; Smak *AA 35*, 357; van der Woerd and van Paradijs *MN 224*,271).

Many authors continued to construct time-dependent accretion disk models applicable to dwarf novae (recent reviews: Meyer *IAUColl 89*, Bath *ApSpSc 130*,293) and to compare them with observations. The most sensitive test involves the rise to outburst. Pringle *et al* (*MN 221*,169) concluded that the disk instability models are unable to reproduce observations of VW Hyi during that phase but Meyer-Hofmeister (*AAp 175*,113) and Meyer-Hofmeister and Meyer (*AAp* in press) showed that when proper opacities are used at low temperatures the agreement becomes satisfactory.

Progress has been reported in the theory of the boundary layer and its X-ray emission (Patterson and Raymond *ApJ 292*, 535 and 550; King and Shaviv *Nature 308*; King *et al. Nature 313*,290; review: Shaviv *ApSpSc 130*,303) and in the theory of accretion in magnetic CV's (reviews: King in *ESA Workshop on Recent Results on CV's*; Hameury *et al. ApSpSc 131*,583).

The TNR theory of the nova outbursts has been significantly modified. Shara *et al.* (*ApJ 294*,271) identified Nova CK Vul 1670, the oldest of all historic novae and determined its absolute magnitude at M_R=10.4. Thus CK Vul is now more than 100 times fainter than post-novae of the 20th century, its present accretion rate being accordingly also very low ($\approx 10^{-12}$ M⊙/yr). Together with the less extreme case of Nova WY Sge 1783 (Shara *et al. ApJ 282*,763), this was used as an evidence by Shara *et al.* (*ApJ 311*,163), Prialnik and Shara (*ApJ 311*,172), and Livio and Shara (*ApJ* in press) to formulate the hibernation theory for novae: The high accretion rates (10^{-8} M⊙/yr) are maintained only briefly (100 yrs) before and after outburst, while during millenia between outbursts novae hibernate at much lower rates. The long duration of the hibernation phase provides an explanation for the CNO enrichment and explains the observed diversity among novae. Longer hibernation times lead to stronger enrichments and more violent outbursts of the fast nova type.

E. ε AURIGAE (R.E. Stencel)

The following is a brief update to reports published in *Highlights of Astronomy* 7,143. There have been several important post-eclipse observations which are affecting overall interpretation.

1. Voyager re-observation confirms presence of hot star in far ultraviolet. Altner and Polidan report a new far UV spectrum obtained recently with the UVS on one of the Voyager spacecraft now in the outer solar system. Although of low S/N, it matches a previous Voyager spectrum of Dzeta Oph, a reddened late O-type star. This supports previous analysis by Altner *et al.* (*AApSup 65*,199) of a hot continuum in IUE observations. Comparison observations of Canopus are planned. Alther also reports continuing IUE observations and failure to detect continuum changes on very short timescales.

2. Infrared monitoring fails to detect increasing temperatures as hotter part of disk moves into view with approaching quadrature. Backman reports, in a private communication, that his continued shortwave infrared monitoring of the system has failed to show any color temperature changes since the end of eclipse, as predicted quadrature approaches. He estimates that nearly 30% of the F-star illuminated disk is visible and that a temperature increase would have been measurable by mid 1987.

3. Continued optical photometry and polarimetry reveal that the F supergiant is clearly a non-radial pulsator with various periods. Hopkins, Kemp and collaborators report that their monitoring shows unambiguous power spectrum peaks corresponding to 61, 80, 96, 129, 233 and 485 days, which support the suggestion by

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Ferro (*MN 216*,571) of irregular variations. The new work is reported in Kemp *et al. ApJ 300*,L11, and Krause *et al. BAAS 19*,752.

4. Some additional important papers are: Saito *et al. PASJ 39*,135 - low mass solutions for ϵ Aur, but is it consistent with non-radial pulsations reported by Kemp *et al.*? See also a series of papers which appeared in *ApSpSc 120-123*. Quantitative optical spectroscopy: Lambert and Sawyer *PASP 98*,389; Thompson *et al.* 1987 preprint.

F. BINARY PULSARS (V. Trimble)

For the first seven years after their discovery, all pulsars were known (from absence of variable Doppler shifts of their periods) to be single stars. This was not surprising since, on the one hand, the violence of a supernova explosion might well disrupt even a close system, and, on the other hand, the wind of a normal companion would have a sufficiently high plasma frequency to keep pulsed radio emission from reaching us. Then, in late 1974, came "the" binary pulsar, 1913+16 (*ApJ 195*, L51). After several years of splendid isolation, it was joined by others, and data have now been published for seven binaries (*Nature 322*,712 and 714) and two single millisecond pulsars (*Nature 300*,615; *IAUC* 4401), thought to be closely related to the binaries. Their status relative to pulsars in general has been elegantly reviewed by Taylor and Stinebring (*AnnRevAAp 24*,285).The companions are, in all cases, white dwarfs or second neutron stars, so that ambient gas does not prevent radio wave propagation.

Binary (and msec) pulsars comprise only about 2% of currently catalogued objects, but, because they are fainter than average by a factor of about 10 (that is the known ones all have rather small dispersion measures; Taylor, *IAUSymp 125*) their real incidence must be larger, probably about 10%, the actual distribution of pulsar periods probably being bimodal (*ApJ 311*,694; *CurrSci 55*,327). The faintness is associated with smaller-than-average period derivatives and calculated magnetic fields of $10^{8.5-11.5}$ G *vs.* 10^{12} G or more typical of single objects. The binary and msec pulsars tend also to have rather small velocities and distances from the galactic plane.

The binary and msec pulsars are important in two ways. First, they provide exceedingly accurate clocks, the precision of terrestrial time standards now setting the limit to how well they can be measured (*Nature 315*,547). The absence of jitter in the phase and period show that any sea of gravitational radiation in which these pulsars are immersed must have energy density over a wide range of wavelengths considerably less than that needed to close the universe (*ApJ 265*,L35; *ApJ 315*,149; Taylor, *IAUSymp 125*). "The" binary 1913+16 shows a relativistic rotation of the line of apsides of about 4^{o}/yr (vs. 43"/century for Mercury) and a gradual shrinkage of its orbit attributable to energy lost by gravitational radiation, as well as other relativistic effects (*PRL 52*,1348; Taylor, *IAUSymp 125*). These provide confirmation that general relativity (including the quadrupole formula for gravitational radiation emission) is an accurate picture of the way gravitation really works. In addition, the relativistic effects depend sensitively on the component masses, telling us that 1913+16 contains neutron stars of 1.45 and 1.38M⊙. Similar effects in 2303+46 currently place the total system mass at 3±1M⊙; precision of the determination will improve as t^2 but probably never rival that of the shorter period system. These masses require the neutron star equation of state to be somewhat harder than might have been thought on other grounds (*PRL 57*,1120).

Second, properties of the binary and millisecond pulsars tell us a good deal about the evolution of pulsars and of binary systems in general. A number of discussions have been published (*JApA 5*,235; *ApJ 308*,680; *AAp 173*,279; van den Heuvel in *IAUSymp 125*; *SovAstrAJ 29*,645; *Nature 300*,720) including some that disagree with the majority (*AAp 177*,163, *ApSpSc 128*,363). There are several main points, each with a certain amount of observational support. Pulsars are born (not neces-

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sarily as very fast rotators, *JApA 1*,25) with fields in excess of 10^{12} G, which decay in 10^{6-7} yrs to below 10^{10} G but not less than $10^{8.5}$ G (*Nature 322*,153) at the same time that the rotation periods lengthen to several seconds; single pulsars become extinct at this point. But a significant subset can (a) form in close binaries without the supernova event disrupting the system, (b) form peacefully in close binaries through mass transfer driving a white dwarf above the Chandrasekhar limit (*ApJ 305*,235), or (c) acquire companions by capture in dense environments like globular clusters. Mass transfer onto these neutron stars will not only produce the observed X-ray binaries but also spin the neutron star back up to rotation periods in the msec range. Thus, when the companion evolves to a white dwarf or neutron star and ceases to provide interfering gas, the rejuvenated neutron star will once again function as a short-period (but weak field) pulsar. The known binary pulsars can all be fitted into various phases of this picture for systems of widely varying initial masses. The identity of the companion as WD or NS can be predicted from the orbit parameters (*Nature 325*,416) and is confirmed by optical identification for three of the WDs (*ApJ 306*,L85; *Nature 324*,127) and absence thereof for the two NSs. Two of the three WDs are quite cool (old) providing confirmation that neutron star magnetic fields need not disappear completely even in several billion years. In addition, it is possible for the two stars to coalesce or be tidally disrupted, leaving isolated msec pulsars like the two seen so far (Romani, Kulkarni and Blandford, subm. to *Nature*).

5. Statistical Investigations (A.H. Batten)

A number of studies of binary incidence in specific groups of stars have been published (e.g. *ApJSup 59*,229; *61*,419; and *64*,487). One of the more important is the new study, by Stryker *et al.*, of binary frequency among population II stars. From discussion of new data and re-discussion of older data, and by application of more refined statistical tests for the variability of velocities, Stryker *et al.* conclude that the binary frequency amongst these stars is around 30% - distinctly higher than earlier estimates.

Griffin (in *Interacting Binaries*, p.1) considered the distribution of the orbital periods of binaries observed by himself. He finds that the median period of this group of binaries is appreciably longer than that of the well-observed systems listed in the *Seventh Catalogue* and the addition of the new systems changes noticeably the period distribution of spectroscopic binaries as a whole. This shows that observational selection can be very specific to the technique of observation that is used. It now appears less likely that there is a sharp division between spectroscopic and visual binaries.

Morbey and Griffin (*ApJ 317*,343) have published an important paper in which they develop statistical tests of the reliability of orbital elements (especially the periods) derived from a limited number of observations. They apply these tests to the study of duplicity among solar-type stars published some years ago by Abt and Levy (*ApJSup 30*,273) and are led to question the reality of many of the orbital elements published there. By implication, the results cast doubt on deductions made from similar surveys by several authors. Abt (*ApJ 317*,353) argues that the effect on our estimates of binary incidence will not be large, because if stricter criteria are adopted in assessing the variability of the velocity of a given star, their effect will to some extent be balanced by the need to make larger corrections for undetected binaries. Nevertheless, the new analysis re-opens the question of binary frequency in various groups of stars and underlines the need for an adequate number of observations of each star included in any survey.

Scarfe (*JRASC 80*,257) has examined again the distribution of mass-ratios in spectroscopic binaries, found by Trimble (*Obs 98*,163) to be bimodal with peaks near mass-ratios of unity and 0.3 - although recently (in *Interacting Binaries*, p.393) she suggested that we do not yet know the true distribution. Scarfe sug-

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gests that binaries showing two spectra are much more likely to have their orbits *determined than those showing only one, and that this will create an artificial* excess of binaries with nearly equally luminous components in our catalogues. This excess will also, for the most part, consist of binaries with mass-ratios near unity. Proper allowance for this selection effect, Scarfe argues, may appreciably change the observed distribution of mass-ratios.

A common theme in these investigations seems to be the re-opening of questions that we thought had been, at least provisionally, answered. A combination of new observing techniques and more refined statistical analyses has made this re-opening possible. The next decade or so may well see appreciable advances in our knowledge of binary-star statistics.

6. Origin and Evolution

A. ORIGIN OF BINARIES (R.H. Durisen)

As *reviewed in* Black and Matthews (*Protostars and Planets II*) *and in* Hollenback and Thronson (*Interstellar Processes*), rapid strides have been made in understanding the mechanisms and conditions for star formation. However, the processes which determine whether single or multiple stars form remain elusive, in part because they seem to occur during the enshrouded collapse and accretion phases. By the *time* Young Stellar Objects (YSO's) *become visible, their binary frequency for* semimajor axes $\gtrsim 1$ AU is roughly similar to that of Main Sequence stars to within statistical uncertainties (Hartmann, private communication). Detections among pre-Main Sequence stars now include several close spectroscopic binaries (e.g. Popper *ApJ 313*,L81, Marschall and Mathieu *BAAS 19*,707).

Dynamic collapse from uniformly rotating, uniform density protostellar clouds can certainly produce binary and multiple systems (e.g. Tohline *Fund.Cosm. Phys. 8*,1; Boss *ApJSup 62*,519). Progress is being made in formulating general criteria for fragmentation (Miyama *et al. ApJ 279*,621; Larson *MN 214*,379; Hachisu and Eriguchi *AAp 140*,259; Tohline *Icarus 61*,10; Hachisu *et al. ApJ* in press). However, Shu and his collaborators (*AnnRevAAp 25*) argue for inside-out collapse from centrally condensed molecular cloud cores produced quasistatically by ambipolar diffusion. With centrally condensed initial conditions, single stars form first and later become surrounded by massive disks as the accretion proceeds. Boss (*ApJ 319*,149) *has confirmed that no direct fragmentation then occurs during collapse.*

Production of very close binaries by classical fission of a rapidly rotating star seems unlikely for both observational and theoretical reasons. Rotation rates of YSO's are too low for them to reach fission instabilities during pre-Main Sequence *contraction* (Bouvier *et al. AAp 165*,10; Hartmann *et al. ApJ 309*,275). Numerical hydrodynamic simulations to date show that barlike fission instabilities do not produce binaries (Durisen *et al. ApJ 305*,281; Williams and Tohline *ApJ 315*,594). A detached ring or disk forms instead via spiral arm ejection, while gravitational torques suppress binary formation. Nevertheless, Lebovitz (*ApJ 275*,316, *ApJ 284*,364, *Geo.Ap.F.Dyn. 38*,15) *and* Eriguchi *and* Hachisu (*AAp 142*,256) *continue* to elucidate other bifurcations and instability points that have yet to be tested, and it remains possible that some of these could produce binary fission.

As cited in the Shu *et al.* review, abundant evidence now exists for Solar *System-sized disks around both protostars and* YSO's. *The spectra of some disks* cannot be explained by simple viscous dissipation or reprocessed starlight (Adams *et al. ApJ 312*,788). These "active" disks are probably massive (a few tenths M⊙ or more) and may be undergoing some form of instability or wave transport. Perhaps stellar companions can form from massive circumstellar disks by mechanisms yet to *be understood. Unexpected instabilities leading to fragmentation in rotating disks* and tori continue to be discovered (e.g. Papaloizou and Pringle *MN 208*,721, *MN 213*,799; Goldreich *et al. MN 221*,339; Hawley *MN 225*,677). Comparisons of the

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binary statistics of classical versus naked T Tauri stars (Walters *PASP 99*,31) should be very useful in this context.

The above discussion suggests that, during the process of star formation, binaries might form by direct fragmentation during collapse if initial cloud conditions are uniform or by fragmentation of a massive circumstellar disk if the protostellar clouds are centrally condensed. The first mode of binary formation is relatively well established theoretically. Detailed mechanisms for the second mode have yet to be proposed. Observations of protostars and the clouds in which they are embedded should help to clarify whether initial cloud conditions favor one, the other, or a mix of the two modes. Once a wide ($\gtrsim$ 1 AU) binary forms by either mode, gravitational torques (Larson *MN 206*,197; Boss *MN 209*,543) or magnetic torques (e.g. Tutukov *Astrofizika 20*,573; Iben and Tutukov *ApJ 284*,719; Moss *MN 218*,247) could cause the system to evolve to a more compact state.

Close binaries can also be formed by tidal capture in dense stellar systems. In star forming regions, the stellar densities are too low to form an appreciable number of close binaries by this method. The application to globular clusters is the best studied case (Krolik *ApJ 282*,452; van der Woerd and van den Heuvel *AAp 132*,361). Direct evidence of binarity for two globular cluster X-ray sources (see the review by Grindlay *IAUSymp 126*) confirms that capture processes have been active (Verbunt *ApJ 312*,L23; Bailyn and Grindlay *ApJ 316*,L25). Several groups have reinvestigated the physics of tidal capture (Lee and Ostriker *ApJ 310*,176; McMillan *et al. ApJ 318*,261). New cross sections and rates have been applied to dynamical models of globular cluster evolution (Hut and Inagaki *ApJ 298*,502; Statler *et al. ApJ 316*,626; Lee *ApJ 319*,772).

B. EVOLUTION OF CLOSE BINARIES (R.F. Webbink)

Overviews of the structure and evolution of binary stars have been published by Boyle (*Vistas in Astr. 27*,149), Webbink (*Interacting Binary Stars*, p.39), and Eggleton (*The Evolution of Galactic X-Ray Binaries*, p.87). Notable reviews of the evolution of W UMa binaries were published by Smith (*QJRAS 25*,405) and Mochnacki (*Interacting Binaries*, p.51), of X-ray binaries by van den Heuvel (*The Evolution of Galactic X-Ray Binaries*, p.107) and Sutantyo (*ApSpSc 118*,257), and of semi-detached binaries generally, but Algol-type systems in particular, by De Greve (*SpScRev 43*,139).

New approaches to a number of difficult physical problems connected with binary star evolution have been made recently. The hydrodynamical structure and stability of mass flow through the inner Lagrangian point was modeled by Edwards (*MN 212*,623; *226*,95), who found Bath-type instability in the outflow from a 1M⊙ star, and by Gilliland (*ApJ 292*,522), who however found no such instability. Papaloizou and Savonije (*MN 213*,85) and Rocca (*AAp 175*,81) studied the excitation of g-mode pulsations by tides, and their role in synchronization, subjects reviewed by Savonije and Papaloizou (*Interacting Binaries*, p.83). We note also renewed interest in the tidal mass transfer in binaries with eccentric orbits, the subject of numerical simulations by Brown and Boyle (*AAp 141*,369) and by Boyle and Walker (*MN 222*,559), and of analytic work by Dolginov and Smel'chakova (*AZh 62*,301).

Evolutionary sequences of massive binaries, including the effects of mass loss in a stellar wind and of convective overshooting, were published by Doom (*AAp 138*,101) and Sybesma (*AAp 142*,171; *159*,108; *168*,147). Hellings (*ApSpSc 104*,83) used thermal equilibrium model sequences to study the evolution of a grid of massive close binaries through case B mass transfer. Nakamura and Nakamura (*ApSpSc 104*,367; *134*,161; *134*,219) evolve both components of a number of models of a 20.4M⊙ (total mass) binary, differing in mass ratio and orbital angular momentum, but all evolving in case A; all evolve rapidly into deep contact.

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The evolution of intermediate-mass binaries leading to helium-star mass transfer remnants, and the subsequent evolution of those remnants, are the subjects of studies by Iben and Tutukov (*ApJSup 58*,661), van der Linden (*AAp 178*, 170), and Habets (*AAp 165*,95). Remnants of intermediate mass (0.75-2.1M⊙ in the calculations by Iben and Tutukov) fill their Roche lobes a second time (case BB mass transfer), whereas lower-mass remnants do not. Habets finds that a more massive remnant, 2.5M⊙, evolves to neon ignition, and presumably beyond to core collapse and neutron star formation; he suggests that low-eccentricity Be star X-ray binaries may originate in this way. Uomoto (*ApJ 310*,L35) proposes that Type Ib supernovae are produced by this type of core collapse of a helium star. Among slightly less massive progenitors, Iben (*ApJ 304*,201) finds that if the initial mass transfer is delayed beyond the core helium burning phase, but occurs before the second dredge-up begins, the CO white dwarf remnant may be greater in mass than that produced by single stars of the same initial mass. Iben *et al*. (*ApJ 304*, 217) show that helium star remnants of mass transfer occupy the same reaches in the Hertzsprung-Russell diagram as subdwarf O and B stars. Tutukov (*IAUColl 87*, p.483) reviews the binary origin of helium rich stars of this type, among others.

The role of magnetic stellar winds in the evolution of Algol-type binaries (and other low-mass binaries as well) has been explored by Iben and Tutukov (*ApJ 284*,719) and Krajcheva *et al*. (*Astrofizika 24*,287), and seems to offer a plausible explanation for the degree of angular momentum loss needed to understand the evolutionary status of observed systems. Pastetter (Thesis, Munich) has modeled the early phases of mass transfer from a thermally-pulsing asymptotic branch giant. In the event that the accretor is an object of planetary mass, and becomes engulfed by the envelope of the giant, Soker *et al* (*MN 210*,189) suggest it may grow to stellar mass, evolving ultimately to become the donor star of a short-period cataclysmic variable. Iben and Tutukov (*ApJ 311*,753) have derived a white dwarf mass distribution produced by binary evolution.

The secular evolution of cataclysmic binaries remains a topic of great interest. A number of studies (Verbunt *MN 209*,227; Fedorova and Yungelson *ApSpSc 103*,125; *107*,207; *Nauchn. Inf. 57*,64; Ritter *AAp 145*,227) have concentrated on constraining the form of the magnetic breaking law so as to reproduce the absence of orbital periods between 2 and 3 hours among cataclysmic binaries. According to van Paradijs (*MN 218*,31P), magnetic torques on the secondaries in these systems could be so great that tidal torques cannot maintain synchronous rotation, but Czerny and King (*MN 221*,55P) respond that the observed mass transfer rates cannot then be explained. The possibility that cataclysmic binaries evolve through cycles of activity, appearing variously in nova-like, dwarf nova, and perhaps even inactive states, was elaborated in the hibernation model of Shara *et al*. (*ApJ 311*,163). Prialnik and Shara (*ApJ 311*,172) showed that such cyclic accretion is capable of producing nova outbursts which sustained rapid accretion suppresses. Sion (*ApJ 297*,538) finds that the luminosities of white dwarfs in low-$\dot{M}$ systems are consistent with accretion rates of 10^{-11} to 10^{-9} M⊙/yr over nova outburst recurrence time scales, and MacDonald (*ApJ 305*,251) estimates that angular momentum loses in nova explosions can dominate secular evolution at orbital periods below 6 hours. Nelson *et al*. (*ApJ 299*,658) studied the influence of rotation and tidal distortion on the structure of short-period cataclysmics, confirming that the 81-min. orbital period limit is produced by gravitational-radiation-driven evolution. Ritter (*AAp 148*,207) showed that absorption of angular momentum by the accreting white dwarf can enhance mass transfer rates, and also explored the evolutionary implications of the properties of pre-cataclysmic binaries. He has comprehensively reviewed the secular evolution of cataclysmic binaries (*High Energy Astrophysics and Cosmology*, p.207; *The Evolution of Galactic X-Ray Binaries*, p.271).

The secular evolution of magnetic cataclysmic variables poses special problems. There is a growing consensus that asynchronous rotators (the DQ Her stars) and synchronous rotators (the AM Her stars) have comparable magnetic moments, and

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that the former tend to evolve toward the latter state (Chanmugan and Ray *ApJ 285*, 252; King *et al. MN 213*,181; Hameury *et al. ApJ 316*,275). Campbell (*MN 211*,69; *211*,83; *215*,509; *219*,589) continued his studies of the nature of magnetic synchronization; Kaburaki (*ApSpSc 119*,85) proposed a new electrodynamical synchronization mechanism. King and Lasota (*AAp 140*,L16) suggest that the high/low state dichotomy of these systems is produced by X-ray heating of the secondary.

Several papers explore the dependence of the minimum orbital period of compact binaries on the degree of hydrogen-deficiency of the donor star (Rappaport and Joss *ApJ 283*,232; Sienkiewicz *AA 34*,325; Nelson *et al. ApJ 304*,231). These results have been applied to low-mass X-ray binaries and systems like GP Com, but Tutukov *et al.* (*PisAZh 11*,123) and Savonije *et al.* (*AAp 155*,51) suggest that their donor stars may not be degenerate at all, but helium main sequence stars. Papers by Khokhlov and Ergma (*PisAZh 12*,366), Iben and Tutukov (*ApJ 313*,727), and Iben *et al.* (*ApJ 317*,717) explore the possibility that helium star + CO white dwarf binaries produce Type Ib supernovae.

Considerable interest has been generated in the possibility that double white dwarfs may be progenitors of Type Ia supernovae. MacDonald (*ApJ 283*,241) showed that the white dwarfs in most cataclysmic binaries probably decrease in mass in the long term, and so are unlikely progenitors. Published studies of accretion of carbon and oxygen onto CO white dwarfs (Nomoto and Iben *ApJ 297*,531; Saio and Nomoto *AAp 150*,L21; Khokhlov *PisAZh 11*,755; Kawai *et al. ApJ 315*,229) agree that, for accretion rates in excess of 2×10^{-6} M☉/yr, up to Eddington-limited rates, lead to non-degenerate carbon ignition in the accreted envelope, and not to a carbon deflagration supernova. Merger models by Hachisu *et al.* (*ApJ 308*,161) however indicate rapid formation of a common envelope and overflow of the outer Lagrangian point. They suggest that CO white dwarf pairs exceeding 2.4M☉ may yet reach carbon deflagration. Tornambe and Matteucci (*MN 223*,69) nevertheless find the SN I rate predicted by the double degenerate CO dwarf model falls short of the local rate by a factor of ten.

The very small period derivatives of known millisecond pulsars indicate anomalously weak magnetic fields, prompting the suggestion that they have been spun up in binary systems. Evolutionary models involving mass transfer from a low-mass giant successfully reproduce the properties of millisecond pulsars known to be in long-period binary systems (de Kool and van Paradijs *AAp 173*,279), but PSR 1937+214 is almost certainly now single. Ruderman and Shaham (*ApJ 289*,244) suggest that it formerly had a very low mass degenerate donor, which became dynamically unstable owing to angular momentum loss to an accretion disk. However, Taam and Wade (*ApJ 293*,504) find this instability very model-dependent, and Bonsema and van den Heuvel (*AAp 146*,L3) argue that this millisecond pulsar could only have been spun up by dynamical merger of a massive (>0.66M☉) white dwarf companion.

Krolik (*ApJ 282*,452), Krolik *et al.* (*ApJ 282*,466), Verbunt (*ApJ 312*,L23), and Bailyn and Grindlay (*ApJ 316*,L25) have explored the tidal or collisional formation of binaries in globular star clusters, the latter two papers specifically addressing the 685-second X-ray binary in NGC 6624. In such a dense stellar environment, encounters with a third star can be an important mechanism driving evolution (Hut and Paczyński *ApJ 282*,675; Donnison *MN 210*,915). Bailyn and Grindlay (*ApJ 312*,748) and Bailyn (*ApJ 317*,737) also examine the evolutionary consequences of a bound third star.

Finally, we note the introduction of interacting triple star models to account for the peculiar binaries: ε Aur (Eggleton and Pringle *ApJ 288*,275), A0620-00 (Eggleton and Verbunt *MN 220*,13P), and SS 433 (Fabian *et al. ApJ 305*,333).

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